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CAUSAL FACTORS IN MICROBIOLOGICAL LABORATORY ACCIDENTS AND INFECTIONS

G. Briggs Phillips

APRIL 1965

UNITED STATES ARMY
BIOLOGICAL LABORATORIES
FORT DETRICK

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U.S. ARMY BIOLOGICAL LABORATORIES
Fort Detrick, Frederick, Maryland

MISCELLANEOUS PUBLICATION 2

CAUSAL FACTORS IN MICROBIOLOGICAL LABORATORY ACCIDENTS AND INFECTIONS

G. Briggs Phillips

Industrial Health and Safety Di
DIRECTORATE OF INDUSTRIAL HEALTH AND SAFETY

Project 1C622401A072

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ABSTRACT

This research was conducted to uncover causal factors of accidental infections and injuries in microbiological laboratories. Less than 20 per cent of the infections were caused by recognized and recorded accidents. As many as 80 per cent of the infections were caused by unsafe acts that occurred without realization or recognition. These are described as "micro-mistakes" resulting in the release of undetected amounts of pathogens to the workers' environment. More than three-quarters of the injuries were caused by unsafe acts. Unsafe conditions caused 10 per cent of the accidents. Dried cultures, infected eggs, and aerosolized cultures were the most hazardous forms of infectious microorganisms. Younger workers and those with less technical training experienced more accidents than older workers or those with more training. Interviews with accident-involved and accident-free persons provided insight into the role of human factors. Accident-involved persons tended to lack accident perception ability and to be inflexible in their work habits. They also were inclined toward excessive risk taking, working at excessive speeds, and intentional violation of regulations. Accident-free workers were more conservative in evaluating safety and seemed able to develop defensive work habits.

DIGEST

This research was conducted to uncover causal factors of ac[illegible] and injuries in microbiological laboratories. It included a re[illegible] ture, collection of data from four institutions, study of data [illegible] Biological Laboratories at Fort Detrick, and an interview wit[illegible] and accident-free laboratory employees.

The significance of the infection problem is illustrated b[illegible] surveys of infections, and by epidemics of laboratory disease [illegible] the occurrence of laboratory injuries is less documented, pers[illegible] the usual work hazards, except that injury in the presence of [illegible] double jeopardy.

Accident data compiled from literature [illegible]ences and from [illegible] institutions were compared with those [illegible] at Fort Detrick. [illegible] was made of 1218 Fort Detrick accidents [illegible]ng between 1959 a[illegible] cation of data followed a system recom[illegible] the American Sta[illegible] The accident-involved and accident-free [illegible] were compared fol[illegible] interview with each subject.

There was good agreement among the [illegible] various sources [illegible] accident classes, (ii) occupations of [illegible], (iii) severity an[illegible] and infections, (iv) accident agents, (v) [illegible] and "unknown" cau[illegible] (vi) occupational diseases, (vii) [illegible]ured, and (viii) [illegible] Less than 20 per cent of the infections [illegible]sed by recognize[illegible] dents. As many as 80 per cent of the [illegible] were caused by [illegible] occurred without realization or rec[illegible]. These are describ[illegible] mistakes" that result in the release of [illegible]ted amounts of i[illegible] the workers' environment.

Lacerations, burns, and strains acc[illegible] for most laborat[illegible] than three-quarters of the injuries were [illegible] by unsafe acts [illegible] unsafe acts were (i) removing, alter[illegible] using safety e[illegible] forming operations prohibited by re[illegible] (iii) failure [illegible] devices. Unsafe conditions caused [illegible] cent of the ac[illegible]

Dried cultures, infected eggs, and [illegible]zed cultures were [illegible] forms of infectious microorganisms. [illegible]at routine dilut[illegible] cedures or working with infected eggs [illegible] most hazardous [illegible]er people with less technical training experience[illegible] accidents than ol[illegible] with more training. Technicians and animal caretakers were involved in [illegible] accidents twice as frequently as expected from [illegible]ribution in the exposed population.

Comparison of the results of in[illegible] 33 accident-involved and 33 accident-free persons provided cause [illegible] agreed with that from accident reports but provided more information on huma[illegible] involvement. Comparison of the two groups revealed that accident-involved [illegible] tended to lack accident perception ability and to be inflexible in their [illegible]s. They were inclined toward excessive risk taking, working at excessive [illegible] and intentional violation of regulations. Accident-free workers were [illegible]ative in evaluating safety efficiency and seemed able to develop defensive [illegible]. Their approach to the human factors control was reflected in awareness [illegible] respect for the laboratory hazards and safety regulations.

The causal information developed provides a basis for recommendations to improve [illegible] in infectious disease laboratories and suggestions for further research. [illegible] and enforcement techniques are important, but the greatest [illegible] education of technical students. However, more research [illegible] of laboratory accidents can be more effectively [illegible]

[illegible] was used as a basis for the preparation [illegible] microbiological safety, (ii) organi- [illegible] safety rules for infectious disease [illegible]

FOREWORD

Technology in the handling of microorganisms infectious to man has undergone revolutionary changes during the past 20 years. Laboratories serving the medical, public health, and veterinary professions have played an increasingly important role in man's struggle to cope with infectious diseases. These laboratories perform diagnostic services, produce vaccines, develop chemotherapeutic agents, operate in the area of national defense, serve as teaching centers, and are the instrument of the epidemiologist in controlling diseases in the population.

Historically, the changing pattern in human infectious diseases has produced parallel changes in the operation of infectious disease laboratories. Classical diseases such as smallpox, diphtheria, typhoid fever, tuberculosis, and poliomyelitis are being brought under control in many parts of the world because of improvements in the standard of living, the application of modern sanitation methods, and immunization. However, since these diseases have not been eradicated, laboratories are very much involved in their detection and control—work that increases in complexity as more diagnostic tests are used and as science learns how adaptable microbes are in resisting man's attack. In addition, new diseases, particularly virus diseases, have been discovered with alarming regularity, presenting unprecedented challenges for laboratory scientists. We now expect the eventual isolation of the etiological agent of one or more human cancers, a feat that will undoubtedly open a new era for microbiologists and result in many changes in laboratory technology. The present-day infectious disease laboratory, therefore, is different from the laboratory of a few years ago. Moreover, the responsibility of the laboratory director in providing the needed service or the required research is great indeed.

It is not surprising that there would result from laboratory activities with infectious disease agents an interest in the special area of microbiological safety, just as developments in the physical sciences produced a need for specialization in radiological safety. It is surprising, perhaps, that microbiological safety has not progressed to the point where specialized knowledge on accident and infection prevention has been adequately summarized and published in useful form. The investigator feels that matters relating to microbiological safety are appropriately considered within the realm of safety education. Prevention of accidents and infections is a legitimate concern of educators, teachers, and instructors who work or teach in infectious disease laboratories. During the educational process, better than at any other time, laboratory scientists, technicians, and workers who deal with infectious agents can be taught the fundamental tenets of laboratory accident prevention.

The first graduate studies in safety education were done at Columbia University in 1927 and 1929. Streitz's[1] study on safety education in elementary schools and Stack's[2] study relating to secondary schools provided information that was used in developing courses of instruction in safety. Since that time, with our constantly changing and complex society, graduate studies in safety education have reflected a greater degree of specialization. Studies in such diverse areas as traffic, farm, and radiological safety illustrate the application of safety research in areas where

[1]Ruth Streitz, Safety Education in the Elementary School. (Ph.D. Thesis) New York: Columbia University, 1927.

[2]Herbert J. Stack, Safety Education in the Secondary Schools. (Ph.D. Thesis) New York: Columbia University, 1929.

increased knowledge can be used to advantage in education. In the opinion of the investigator the portfolio of educational safety research should include microbiological laboratory safety.

This report deals with only one phase, but perhaps the most important phase, of microbiological laboratory safety: the causes of accidents. To deal adequately with this subject, the study necessarily includes consideration of much other information relating to laboratory accidents and illnesses and the climate in which they occur. Cause investigation is a fundamental and necessary step in an effort to improve safety through education in microbiological laboratories.

ACKNOWLEDGMENTS

It is impossible to list specifically all persons and agencies who generously rendered support throughout the period of this research and during the preparation of this document. To those listed below, I express my thanks for continued support and assistance. To the many whose names are not shown, I nevertheless owe a debt of gratitude.

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The financial support by the S. Blickman Co. of Weehawken, New Jersey, and by the Esso Research Foundation, in addition to that of the U.S. Army Biological Laboratories, enabled the performance of this research. I am particularly indebted to Mr. Bernard Blickman and to the Center for Safety Education for arranging this support. Also, I should like to acknowledge the backing and support for this project over a number of years by Dr. Riley D. Housewright, Scientific Director of the U.S. Army Biological Laboratories.

Among others at Fort Detrick to whom I wish to express my sincere gratitude are Mrs. Madeline D. Warnock for her suggestions regarding the manuscript, Mrs. Esther R. Farmer for her many months of typing and retyping, and Mr. Sam P. Bailey and Professor Dominic Greco for their excellent support in the sorting and cataloging of data. Also the support and services by all of my colleagues of the Industrial Health and Safety Division are acknowledged.

Finally, I wish to express my thanks to all of those persons who participated in the study by reviewing the interview schedule, by supplying records of accidents, or by submitting to personal interview.

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I. PURPOSE OF THE INVESTIGATION AND NATURE AND SIGNIFICANCE OF THE PROBLEM

A. PURPOSE OF THE INVESTIGATION

This study was conducted to identify the causal factors related to accidents and occupational infections occurring in microbiological laboratories.

B. THE PROBLEM DEFINED

1. Subproblems

The study was conducted by consideration of four specific subproblems.

a. Subproblem One

What has previous research revealed regarding causal factors, in terms of unsafe behavior and unsafe conditions, that are important in microbiological laboratory accidents and infections?

b. Subproblem Two

What does a study of accident-involved and accident-free groups reveal in terms of causes of microbiological laboratory accidents?

c. Subproblem Three

What causes of microbiological laboratory accidents were revealed by an analysis of the accident records of the U. S. Army Biological Laboratories?

d. Subproblem Four

What findings were derived from a comparison of the data obtained from these three sources and from a comparison of accident-involved and accident-free groups?

2. Definition of Terms

For the purposes of this study the following terms were defined:

Accident: An event characterized as follows: (i) it is unplanned, (ii) it may or may not result in injury or damage, (iii) it interrupts the efficient completion of an activity, and (iv) it is invariably preceded by unsafe acts, unsafe conditions, or both.

Accident cause: A contributory element or factor that, interacting with other elements or factors, occasions an accident or an injury.

Accident-free person: A person having no reportable laboratory accidents during the two years prior to this study.

Accident-involved person: A person having at least one reportable laboratory accident during the two years prior to this study.

Accident records: Information or data collected by supervisors, laboratory chiefs, or safety department personnel concerning accidents that have occurred in microbiological laboratories. The records are generally concerned with biographical information, background information, accident details, accident outcome (if any), known causal information, and corrective action.

Cause of a disease: Cause in this instance will refer to acts, conditions, or incidents whose modification or elimination would have prevented infection. The technical name of an infectious microorganism will not be spoken of as the cause of a disease.

Causal factor: Any human act or characteristic, mechanical or environmental condition that contributes to the cause of an accident.

Epidemiological approach: A general approach to accident cause analysis that suggests consideration of the interactions and interrelationships of the host, his environment, and accident agencies.

Laboratory illness: A laboratory infection in which clinical symptoms result in loss of work time.

Laboratory infection: The accidental infection of a laboratory worker with an infectious disease, the etiological agent of which is being handled in that laboratory.

Lost-time injury: An accident, other than a laboratory infection, that produces incapacitation severe enough to prevent the involved person from reporting to work on his next regularly scheduled shift.

Microbiological laboratory accident: An event occurring in a microbiological laboratory that is characterized by the four elements of an accident, buy may have the following possible features when the injury or damage is an infectious occupational disease:

1) Any act or condition that allows or causes release of infectious microorganisms to the environment of the laboratory worker and is thereby unsafe.

2) Unsafe acts and unsafe conditions may be m difficult to define and detect than ordinarily would be the case; some may be unknown.

3) The interruption of the activity may be delayed because of the incubation time of the infectious disease.

Non-lost-time infection: A laboratory infection not producing frank clinical symptoms and usually detected only by serological means.

Reportable accident: Includes all laboratory lost-time accidents and those laboratory non-lost-time accidents involving infectious exposure or minor injury. Near-miss accidents are generally not included except in the interview studies.

Unsafe act: An unnecessary exposure to a hazard resulting from the action of an individual. An unsafe act may be a departure from an accepted, normal, or correct procedure or practice, conduct that minimizes the degree of safety normally present, or conduct that unknowingly or in an unsuspected fashion creates a hazard.

Unsafe condition: Any physical condition that, if left uncorrected, may lead or contribute to an accident.

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Unsafe condition: Any physical condition that, if left uncorrected, may lead or contribute to an accident.

3. Basic Assumptions

Two basic assumptions were accepted in advance:

A review of previous research on microbiological laboratory safety and an analysis of the accident records of a large microbiological research institute will reveal causal factors important in formulating accident prevention measures.

Planned interviews with laboratory workers will uncover additional accident causal factors, known or unknown to the worker, that may be useful in loss-prevention measures.

C. INCIDENCE OF THE PROBLEM

The selection of the general area of study was a result of a review of literature on microbiological safety and of some previous research studies published by the investigator.

Two observations influenced the selection of a specific study area. First, in some laboratory situations, where the engineering approach to microbiological safety had been developed to a high degree, it was observed that a substantial infectious hazard problem remained and specific accident causes were generally unknown. This, subjectively, indicated the need for better causal information and the use of other safety approaches, such as education and enforcement. Second, during a 15-month study of laboratory safety in 18 countries, the investigator observed that few laboratories were in possession of cause information suitable for the reduction of microbiological laboratory accidents. Moreover, most teaching institutions do not include microbiological safety in the subject matter of laboratory courses.

D. SIGNIFICANCE OF THE PROBLEM

Increased expenditures for education and increased emphasis on microbiological research portends an increasingly greater demand for safety programs to protect potentially exposed students, researchers, and scientists.

Education in laboratory safety methodology in colleges and universities, as well as safety training for employees on the job, requires, as a background, an adequate body of facts about laboratory hazards, their prevention, and their causes. In a time when there is a recognized shortage of educators and teachers it is appropriate that scientific methodology be applied in efforts to control and reduce accidents to those handling hazardous materials in microbiological laboratories. Moreover, future demands on the educational system signal a need for research information on this subject for use by educators.

Of significance, for example, is the trend toward team research in which persons trained in fields other than microbiology use infectious cultures as tools in the solving of life-science problems.[1] Should the effort to isolate and identify viruses as the etiological agents of certain human cancers be successful, the need to protect research workers would be obvious. Likewise, in the space satellite research program it has been recognized that uncontrolled transfer of microbes between planets is undesirable. In the medical field, a more immediate problem is that of the

[1]R. D. Reid, "Trends in Microbiology," American Institute of Biological Sciences, Bulletin No. 1956.

spread of staphylococci and other infections among hospital personnel and patients. The principles of environmental control applicable in microbiological safety would be helpful in these problems.

It has been principally during the past two decades that attention has been given to the problem of accidents and infections in microbiological laboratories. The former tradition of personal sacrifice is becoming outdated by economic, moral, and legal pressures. In the past few years, it has become clear that laboratory determinations will be accurate only if controlled to the extent that concurrent culture cross-contamination or animal cross-infection can be prevented. This has prompted research helpful in developing techniques and methods that reduce human infectious risks in the laboratory.

Published research in the field of microbiological safety has been devoted principally to evaluating the hazards of various procedures, to surveys of types of laboratory infections, and to development of mechanical protective devices. This research is reported in a variety of technical journals, but has not been readily accepted and used by microbiologists as a group. Moreover, little or no information has been developed on management and administrative principles applicable in this type of hazard situation. There has been no over-all summary and analysis of these subjects to determine the present-day status of microbiological safety and future areas of need. Finally, programs in microbiological safety are attempted by some laboratory institutions, but they are rarely based on accurate causal information developed by systematic study.

The present need is for adequately summarized and evaluated causal information for use by educators teaching students of microbiology and by laboratory directors and others who are responsible for instituting and supervising safety programs in infectious disease laboratories.

Before adequate instructional programs can be prepared and before instructors can effectively incorporate information on infectious hazards into laboratory science courses, educators must have an adequate assessment of the causes of microbiological laboratory accidents and infections.

E. THE RESEARCH RATIONALE

The over-all research used a combination of descriptive survey and group study techniques. The research concept, however, can be described as an epidemiological approach because it emphasizes identification and study of host factors, accident agencies, and environmental conditions present in laboratory accident situations. Moreover, this approach attempts to utilize the various interrelationships and interactions that exist among the host, the agent, and the environment as a means of uncovering factors of importance in causation.

The epidemiological approach has been used to advantage in the study of mental health, disease, nutrition, and recently its use has been proposed for educative processes.[1] Gordon,[2] in 1949, was the first to propose its use in accident

[1] A. R. Leonard, "An Epidemiologic Approach to Health Education," American Journal of Public Health, 51, (1961) pp. 1555-1560.

[2] J. E. Gordon, "The Epidemiology of Accidents," American Journal of Public Health, 39, (1949) pp. 504-515.

prevention. Other investigators, notably McFarland,[1] have used the general concepts of the epidemiological approach in specific safety areas. Although some criticism of this approach to accident research has been expressed,[2] based primarily on the tendency to consider only single causal agents, it should be noted that some highly sound inferences of causality have resulted from epidemiological studies.

Specific to the epidemiological method, various authors have discussed means of establishing cause. Phair and Sterling,[3] for example, discussed some fundamental assumptions that apply and listed the weapons commonly used in cause analysis as (i) comparison of groups, (ii) deductive reasoning, and (iii) reasoning by exclusion. Such broad categories are helpful, but the possible complexities in cause analysis can be expressed more specifically.

Modern writers such as Bunge[4] have viewed "perfect causation" as an abstract conceptual model in the same way that perfect randomness is abstract. Concepts of cause, force, chance, and law are not mutually exclusive and in any scientific analysis they may be intertwined in various ways. Establishment of causation requires the ability to exclude factors that traditionally may be thought of as causes. One such concept is that there is a constant and one-to-one relationship among events whereby causes produce effects. This model (C = E) is too simple for most scientific purposes. Also, the concepts of conjunction, succession, antecedence, and contiguity must be understood in speaking of causes and resultant events. In general, these factors may be identified in connection with an accident and may or may not reflect a causal relationship. This would be related to the medical finding that production of illness in a patient is influenced by his state of immunity as well as by the disease agent.

Regardless of whether the term "epidemiological approach" or another name is used, the rationale of research on causal factors must, in the investigator's view, reflect the fact that accidents occur as a result of combinations of human and environmental factors. Moreover, one must bear in mind that the prime reason for determining cause, in relation to accidents, is to provide a means of intervention that will eliminate the loss. Therefore "causes" *per se* in the accident scene must be understood to be a part of a dynamic system in which there exist all possible degrees of interrelationship and interaction among people, their environment, and other things present in the environment.

Brody[5] has appropriately described the dynamics of accident involvement as follows:

[1] R. A. McFarland, "Epidemiologic Principles Applicable to the Study and Prevention of Child Accidents," *American Journal of Public Health*, 45, (1955) pp. 1302-1308.

[2] B. H. Fox, *Behavioral Approaches to Accident Prevention*, Association for the Aid of Crippled Children, New York, N. Y., (1961) p. 51.

[3] J. J. Phair and T. Sterling, "Epidemiological Methods and Community Air Pollution," *Archives of Environmental Health*, 3, (1961) pp. 267-275.

[4] M. Bunge, "Causality, Chance, and Law," *American Scientist*, 49, (1961), pp. 432-448.

[5] L. Brody, "Methodology and Patterns of Research in Industrial Accidents," *Annals of the New York Academy of Sciences*, 107, (1963) p. 659.

At the root of any accident will be found human factors of one kind or another—physiological, biochemical, psychological. These factors are meaningless, however, without reference to environmental considerations—the nature of the work, the nature of the work organizatization, and "sheer" physical or chemical aspects of the environment. Essentially, the over-all problem of accidents appears to be a matter of functional disharmony or imbalance between man and environment, resulting in a stressful situation.

Thus, the research rationale employed was pointed toward establishing facts about man, environment, and accident agencies in a laboratory work situation and toward an understanding of imbalances or interactions that result in accidents. The particular technique employed for classifying the data followed that recommended by the American Standards Association, but the manipulation of the data in order to reveal causal factors was done in relation to the rationale discussed above.

The concept of interacting factors is helpful in accident cause analysis but complicated by the usual inability to probe deep into stimuli. That is to say that relationships could exist between certain stimuli such as hunger and underlying physiological factors such as blood sugar levels. In accident prevention the problem is one of probing deep enough to find factors that can be controlled or manipulated without being enmeshed in subfactors that are impractical or impossible to control.

Statistical correlation is utilized in the epidemiological approach to establish tentative causal relationships. However, "systematic relations" is also an appropriate term because it includes functional relations, interactions, and causation, and permits further proof of causation when high correlations are found between two factors that may be cause and event respectively. If two traits or events (x and y) are shown by analysis to have a high correlation value, considering this as a statistical systematic relation will allow trial of a number of hypotheses concerning the nature of the relationships.

The above represents the approximate conceptual model the investigator used in studying accident cause factors. It begins with the establishment of systematic relationships between potential causes and events, and continues through the application of null hypotheses in attempts to eliminate possible relationships other than cause. It is obvious that statistical correlation is sometimes not a sufficient guarantee of causality. Other characteristics of the interrelationship of factors, sometimes of a subjective nature, also are important considerations in substantiating causality.

II. HISTORICAL STATUS AND DEVELOPMENT OF THE PROBLEM

Most of the useful information on microbiological laboratory safety has been developed during the past 20 years. The published information reviewed and analyzed by the investigator was found in widely scattered technical journals. No summaries of microbiological laboratory accident data dealing adequately with accident causes were found. Moreover, available information was mostly about laboratory-acquired infections; almost no information was available on accidents in microbiological laboratories resulting in other types of injuries.

Examination of the literature uncovered more than 600 articles on laboratory infections. These references are concerned primarily with the medical aspects of the infections. Typically, they yield little information on accident causes although they serve to illustrate that infections have long been a problem in infectious disease laboratories.

The earliest recorded laboratory infections were two cases of typhoid fever that occurred in 1885 or 1886 to personnel in the German Imperial Health Service.[1] In 1893 a European physician contracted typhoid fever by aspiration of a culture through a pipette[2] and a case of tetanus occurred in France because of accidental syringe inoculation.[3] Syringe inoculation also caused the first laboratory infection of blastomycosis in 1903.[4] Five references to other cases occurring prior to 1900 were found.

Table 1 deals with the frequency of laboratory infections reported in the literature between 1893 and 1950. It shows the number of reports in each 10-year period, the diseases involved, and the date, when available, of the first isolation of each etiologic agent. The data generally show how the problem of laboratory infections has increased with development of microbiology and with the identification of disease agents.

Figure 1 shows the cumulative frequencies by 20-year intervals for numbers of different diseases reported and for publications reporting laboratory infections These also show how the problem has developed as the science of microbiology has grown.

Historically, the first identification of disease agents frequently has been followed by disease among laboratory personnel. With two diseases (monkey B virus infections[5] and rickettsialpox[6]), the first isolation of the causative agents was

[1] K. Kisskalt, "Laboratory Infections with Typhoid Bacilli," Zeitschrift fur Hygiene und Infektionskrankheiten, 80, (1915) pp. 145-162.

[2] Ibid.

[3] M. J. Nicolas, "Sur un cas de Tetanus Chez l'Homme par Inoculation Accident des Produits Solubies due Bacilli de Nicolaier," Compes Rendus der Seances de la Societe de Biologie, 5, (1893) pp. 844-847

[4] J. Schwarz, G. L. Baum, and N. A. Evans, "Clinical Report of a Case of Blastomycosis of the Skin from Accidental Inoculation," Journal American Medical Association, [illegible] (1903) pp. 1772-1775.

[5] A. B. Sabin and A. M. Wright, "Acute Ascending Myelitis Following Monkey Bite with Isolation of Virus Capable of Reproducing Disease," Journal Experimental Medicine, 59, (1934) pp. 115-136.

[6] S. E. Sulkin and R. M. Pike, "Survey of Laboratory-Acquired Infections," American Journal of Public Health, 41, (1951) p. [illegible]97.

TABLE 1. REFERENCES TO LABORATORY INFECTIONS COMPARED WITH THE YEAR OF ISOLATION OF THE ETIOLOGICAL AGENTS[a]

Period	Number of Publications	Diseases Involved Not Reported in Previous Periods and Date of First Isolation of Etiological Agents When Known[1,2]
1893-1900	5	Brucellosis (1887), cholera (1886), diphtheria (1886), tetanus (1886).
1901-1910	7	Syphilis (1905).
1911-1920	7	Infectious jaundice, plague (1896), tuberculosis (1882).
1921-1930	41	Coccidioidomycosis (1896), dengue (1907), influenza (1892-1933), psittacosis (1930), rat bite fever (1888), scarletina (1923), tularemia (1912), epidemic typhus fever (1916), yellow fever (1901).
1931-1940	80	Anthrax (1876), bacillary dysentery (1898), choriomeningitis (1934), Eastern equine encephalitis (1933), endemic typhus (1920), erysipeloid, infectious bulbar paralysis, louping ill (1930), Kala-azar, leprosy (1874), monkey B virus (1934),[b] Q fever (1939), Rift Valley fever (1930), Rocky Mountain spotted fever (1919),[c] typhoid fever (1880), Western equine encephalitis (1938).
1941-1950	110	Coxsacki virus infections (1948), glanders (1882), gonorrhea (1885), infectious hepatitis (1939), leptospirosis ballum infections (1917), lymphogranuloma venerum infections (1942), mumps (1934), Newcastle disease virus infections (1943), poliomyelitis (1909), rickettsialpox (1946),[b] salmonellosis (1900), Venezuelan equine encephalitis (1943), vibrio fetus infections (1919).

a. Total Number of References 250
   Number of Different Diseases Reported 47
b. The first isolation of etiological agent was from infected laboratory personnel.
c. Discoverer died from infection with the etiological agent.

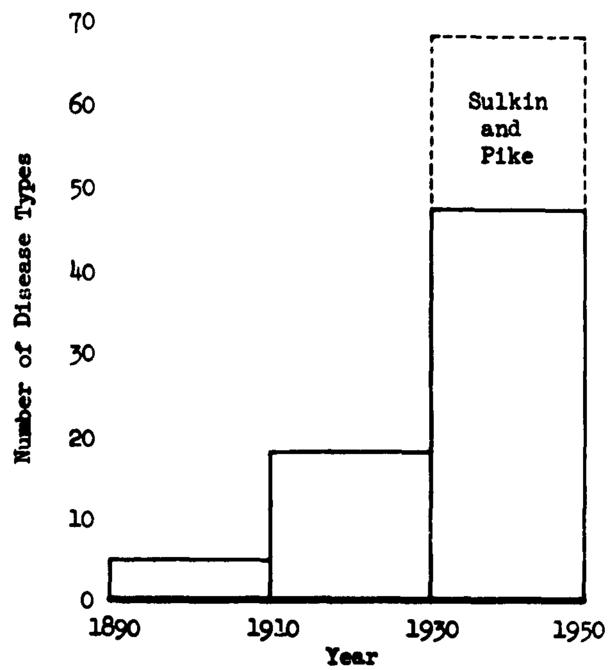
from infected laboratory people. With two other diseases (Q fever[3] and louping ill virus infections[4]), infections in laboratory workers were noted before infections in other human groups. The first reports of human leptospirosis due to Leptrospira

[1]R. S. Breed, E. G. D. Murray, and V. R. Smith, Bergey's Manual of Determinative Bacteriology, 7th Ed., The Williams and Wilkins Co., Baltimore, Md., 1957.

[2]T. M Rivers and F. L. Horsfall, Jr., Viral and Rickettsial Infections of Man, 3rd Ed., J. B. Lippincott Co., Philadelphia, Pa., 1959.

[3]R. E. Dyer, "Filter-Passing-Infectious Agent Isolated from Ticks: Human Infections," Public Health Reports, 53, (1938) p. 2277.

[4]G. Davison, C. Neubauer, and W. W. Hurst, "Meningo-Encephalitis in Man Due to the Louping-Ill Virus," Lancet, 2, (1948) pp. 453-457.



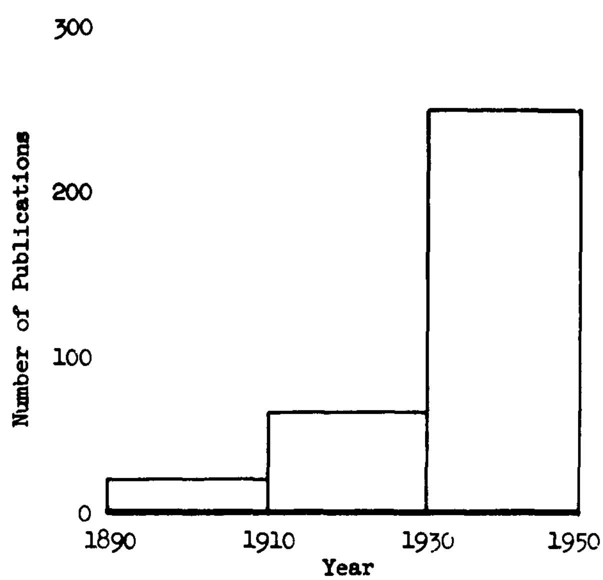


Figure 1. Cumulative Frequencies of Types of Laboratory Diseases and Publications on Laboratory Infections, 1890 - 1950.

icterohemorrhagiae, in 1922, and to Leptospira ballum, in 1949, were from individuals with laboratory-acquired infections.[1,2] More recently, laboratory infections have shown that Plasmodium cynamolgi, not formerly known to be a human pathogen, can cause human malaria[3] and that the salivary gland virus of bats can infect man.[4] Also, from 1953 to 1962 some 69 cases of hepatitis have been documented among persons handling sub-human primates under circumstances where primate-to-human transfer was suspected.[5]

Of specific recent interest are laboratory infections due to microbial preparations that by reason of their long cultivation on artificial media or other reasons were assumed to be attenuated. Thus a strain of typhoid fever was able to infect a medical student after 41 years of artificial cultivation.[6] Two strains of group A streptococci have caused laboratory infections 44 years after their original isolation.[7] Likewise, trachoma virus after 23 egg passages was able to infect when accidentally splashed into the eye of a laboratory worker.[8]

An additional illustration of the role of laboratory infections is the obituary notices announcing the deaths of scientists due to diseases acquired in the laboratory.[9-13]

[1] A. Wadsworth, H. V. Langworthy, F. C. Stewart, A. C. Moore, and M. B. Coleman, Infectious Jaundice Occurring in New York State," Journal American Medical Association, 78, (1922) pp. 1120-1121.

[2] J. W. Wolff, H. Bohlander, and A. C. Ruys, "Researches on Leptospirosis Ballum: the Detection of Urinary Carriers in Laboratory Mice," Antonie V. Leeuwenhock, 15, (1949) pp. 1-13.

[3] D. E. Eyles, G. R. Coatney, and M. E. Getz, "Vivax-Type Malaria Parasite of Macaques Transmissible to Man," Science, 131, (1960) pp. 1812-1813.

[4] S. E. Sulkin, K. F. Burns, D. F. Shelton, and G. Wallis, "Bat Salivary Gland Virus: Infections of Man and Monkey," Texas Reports on Biology and Medicine, 20, (1962) pp. 113-127.

[5] J. R. Held, "Sub-Human Primates in the Transmission of Human Hepatitis," Sixth CDC Biennial Veterinary Conference, Atlanta, Georgia, August 6-10, 1962.

[6] C. L. Olson, S. Gaines, and E. W. Hook, "Laboratory-Acquired Typhoid Fever: Infection with a Laboratory Strain of Salmonella typhosa Isolated Forty-One Years Earlier," Bulletin Johns Hopkins Hospital, 109, (1961) pp. 129-133.

[7] R. M. Pike, S. E. Sulkin, and M. L. Schulze, "Continuing Importance of Laboratory-Acquired Infections," Presented at the annual meeting of the American Public Health Association, St. Louis, Mo., November 14, 1963.

[8] C. H. Smith, "Accidental Laboratory Infection with Trachoma," British Journal Ophthalmology, 42, (1958) pp. 721-722.

[9] Obituary of Dr. A. Macfadlyn, Lancet, 1, (1907) p. 697.

[10] Obituary of Dr. Adrian Stokes, British Medical Journal, 2, (1927) pp. 615-617.

[11] Obituary of Dr. W. A. Young, British Medical Journal, 1, (1928) p. 1005.

[12] Obituary of Anna Pabst, Journal American Medical Association, 106, (1936) p. 129.

[13] "Homenaje a la Memoria de un Martir de la Ciencia," Colombia Universidad Nacional Facultad de Medicine, Revista, 11, (1942-1943) pp. 483-488.

Some information was found in surveys of laboratory-acquired infections and in reports of institutional epidemics. These must be viewed with the knowledge that collection of biometric data is complicated by factors such as non-diagnosed diseases and the absence of channels for reporting infections. Authorities,[1] therefore, believe that instances of laboratory-acquired disease reported in the literature represent only a fraction of those actually occurring.

The Germans were the first to publish collected cases of laboratory infection. In 1915 Kisskalt summarized information about 50 cases of laboratory-acquired typhoid fever obtained by sending a questionnaire to a number of European laboratory directors.[2] An account of 59 additional cases of typhoid fever occurring between 1915 and 1929 was published in 1929 by Kisskalt.[3] That author also reviewed 24 laboratory infections, with three deaths, that were due to other bacterial diseases. In the late 1930's, Draese[4] reviewed 111 laboratory infections, with nine fatalities, occurring in Germany between 1930 and 1937. He also summarized 130 cases of laboratory-acquired typhoid fever and 157 other infections that had been reported previously. Because of their high frequency, Draese declined to list laboratory infections of Weil's disease (leptospirosis) and yellow fever.

In this country, in 1940, Huddleson and Munger[5] published details of an epidemic of brucellosis among students and laboratory personnel at Michigan State College. During the following year Meyer and Eddie[6] summarized 74 laboratory-acquired brucellosis infections. McCoy's[7] earlier publication (in 1930) dealt with an outbreak of psittacosis among employees of the Hygienic Laboratory in Washington, D.C.

A number of laboratory outbreaks of Q fever have been reported in the literature. In 1940, during a 54-day period, 15 of 153 persons working in one laboratory building at the National Institutes of Health developed Q fever.[8] In Italy, during 1946,

[1]S. E. Sulkin, "Laboratory-Acquired Infections," Bacteriological Reviews, 25, (1961) pp. 203-309.

[2]A. Kisskalt, "Laboratory Infections with Typhoid Bacilli," Zeitschrift fur Hygiene und Infektionskrankheiten, 80, (1915) pp. 145-162.

[3]A. Kisskalt, "Laboratoriumsinfektionen mit Typhusbazillen und Anderen Bakterien," Archives fur Hygiene, 101, (1929) pp. 137-160.

[4]K. D. Draese, "Uber Laboratoriumsinfektionen mit Typhusbazillen und Anderen Bakterien," Archives fur Hygiene und Bacteriology, 119-121, (1937-1939) pp. 232-291.

[5]I. F. Huddleson and M. Munger, "A Study of an Epidemic of Brucellosis Due to Brucella melitensis," American Journal of Public Health, 30, (1940) pp. 944-945.

[6]K. F. Meyer and B. Eddie, "Laboratory Infections Due to Brucella," Journal of Infectious Disease, 68, (1941) pp. 24-32.

[7]G. W. McCoy, "Accidental Psittacosis Infection Among the Personnel of the Hygienic Laboratory," Public Health Reports, 45, (1930) pp. 843-845.

[8]J. W. Hornibrook and K. R. Nelson, "An Institutional Outbreak of Pneumonitis. I. Epidemiological and Clinical Studies," Public Health Reports, 55, (1940) pp. 1936-1954.

there were 20 Q fever infections at the 15th U.S. Medical General Laboratory.[1] In the same year there were 16 cases at the laboratories of the Commission on Acute Respiratory Diseases at Fort Bragg, North Carolina.[2] The largest reported outbreak of Q fever occurred in a single building of the National Institutes of Health between December 1945 and May 1946. Huebner[3] reported that 47 persons were infected, including persons who had merely visited the building for a short time. During 1947 and 1948 there were 13 laboratory infections with Q fever at the Bernard Nocht Institute in Hamburg, Germany.[4] Nauck and Weyer reported that the rickettsia strain involved was sent to another German laboratory at Elberfeld where a laboratory epidemic involving about 20 persons occurred. In spite of the fact that R. burnetii has not been widely handled in microbiological laboratories, more than 200 cases of laboratory disease have occurred.

A number of publications have dealt with tuberculosis among medical and laboratory workers. Among these are the studies of Hedvall[5] in Sweden, Smith[6] in England, and Morris,[7] Lim-Yuen,[8] Meade,[9] and Merger[10] on this continent. The most significant survey of laboratory tuberculosis was that of Reid,[11] in 1957, which covered 368 medical laboratories in England. Reid's analysis indicated that the incidence of active pulmonary tuberculosis was three times as high among laboratory personnel exposed to infectious materials as among non-exposed laboratory workers.

[1]F. C. Robbins and R. Rustigan, "Q Fever in the Mediterranean Area: Report of its Occurrence in Allied Troops. IV. A Laboratory Outbreak," American Journal of Hygiene, 44, (1946) pp. 64-71.

[2]Commission on Acute Respiratory Disease, Fort Bragg, N. C., "A Laboratory Outbreak of Q Fever Caused by the Balkan Grippe Strain of Rickettsia burnetii," American Journal of Hygiene, 44, (1946) pp. 123-157.

[3]R. J. Huebner, "Report of an Outbreak of 'Q' Fever at National Institutes of Health," American Journal of Public Health, 37, (1947) pp. 431-440.

[4]E. G. Nauck and F. Weyer, "Laboratory Infections with Q Fever," Deutsche Medizinische Wachenschrift, 7, (1949) pp. 198-202.

[5]E. Hedvall, "The Incidence of T. B. Among Students at Lund University," American Review of Tuberculosis, 41, (1940) pp. 770-780.

[6]G. S. Smith, "Tuberculosis as a Necropsy Room Hazard," Journal of Clinical Pathology, 6, (1953) pp. 132-134.

[7]S. I. Morris, "Tuberculosis as an Occupational Hazard During Medical Training," American Review of Tuberculosis, 54, (1946) pp. 140-158.

[8]D. M. Lim-Yuen, "Tuberculosis in Sanatorium Personnel," American Review of Tuberculosis, 54, (1946) pp. 261-271.

[9]G. B. Meade, "The Prevention of Primary Tuberculosis Infections in Medical Students," American Review of Tuberculosis, 58, (1948) pp. 675-683.

[10]C. Merger, "Hazards Associated with the Handling of Pathogenic Bacteria," Canadian Journal of Laboratory Technology, 18, (1957) pp. 208-210.

[11]D. D. Reid, "Incidence of Tuberculosis Among Workers in Medical Laboratories," British Medical Journal, 2, (1957) pp. 10-14.

Sulkin and Pike,[1] in 1949, summarized information on 222 laboratory infections with viral agents. Twenty-one of the infections were fatal. To date the largest collection of information on laboratory-acquired infections was published in 1951 by Sulkin and Pike.[2] That study listed 1342 laboratory infections, with 69 different infectious agents, that resulted in 39 deaths.

Since 1951, publications on microbiological safety have dealt primarily with studies of hazard-producing situations and the development of protective apparatus and equipment. The most significant recent contributions are those of Wedum,[3] Sulkin,[4] and Chatigny.[5]

While the studies referred to in this chapter illustrate the nature of the infectious hazard problem, most fall short of supplying the causal information needed to formulate realistic preventive measures. In most studies only obvious accident or infection causes have been found. In the Sulkin and Pike survey[6] these accounted for no more than 20 per cent of the tabulated cases.

The problem of unknown causes for laboratory infections has been referred to many times in the literature and is characteristic of both early and current publications on this subject. Table 2, adapted and expanded from that presented originally by Wedum,[7] shows that in most summaries and surveys, the causes of the majority of the infections were unknown. Discovery of these unknowns is one of the most challenging of the problems related to this research.

The current situation in regard to laboratory safety has been described by Wedum[7] as follows:

> In academic laboratories and research areas, definite policies in regard to safety are apt to be poorly developed, unless there is an administrator elsewhere in the organization, or a senior laboratory person who has a persistent interest in this subject. Similarly, safety practices in the university are likely to be haphazard, with attention to some points of danger and no attention to others. This condition also exists to a degree in governmental laboratories, largely due, in my opinion, to the fact that most of

[1]S. E. Sulkin and R. M. Pike, "Viral Infections Contracted in the Laboratory," New England Journal of Medicine, 241, (1949) pp. 205-213.

[2]S. E. Sulkin and R. M. Pike, "Survey of Laboratory Infections," American Journal of Public Health, 41, (1951) pp. 772-773.

[3]A. G. Wedum, "Control of Laboratory Air-Borne Infection," Bacteriological Reviews, 25, (1961) pp. 210-216.

[4]S. E. Sulkin, "Laboratory-Acquired Infections," Bacteriological Reviews, 25, (1961) pp. 203-209.

[5]M. A. Chatigny, Protection Against Infection in the Microbiological Laboratory: Devices and Procedures, in Advances in Applied Microbiology, Vol. 3, edited by Wayne W. Umbreit, Academic Press, New York, N.Y., 1961.

[6]Sulkin and Pike, op. cit., p. 777.

[7]A. G. Wedum, "Policy, Responsibility and Practice in Laboratory Safety," Proceedings of the Second Symposium on Gnotobiotic Technology, University of Notre Dame Press, Notre Dame, Indiana, (1959) p. 117.

TABLE 2. KNOWN AND UNKNOWN CAUSES OF LABORATORY INFECTIONS

Data Source	Percentage of Accidents	
	Known Cause	Unknown Cause
Paneth, 1915	61	39
Sulkin and Pike, 1951	16-20	80-84
Schafer, 1950	16	84
Survey in 18 countries	14	86
Fort Detrick Safety Division reports 1950-1956	30	70
Fort Detrick supervisors' written reports 1953-1956	33	67
Exhaustive investigation of Fort Detrick cases 1955-1957	35	65
Fort Detrick mechanical and chemical lost-time injuries	100	0

the staff receive little or no safety training in the university, and because many governmental career safety officers have no laboratory training. As a result, the development of safe experimental techniques tends to be less emphasized than prevention of fire and property damage.

Wedum also described several stages of development of microbiological safety: first, where there is emphasis on prevention of accidents due to equipment, chemicals, explosions and fire; second, the study of hazards created by microbiological techniques, followed by the development of specialized protective apparatus; and third (the stage not yet developed), the personal involvement of each worker in the safety program. In discussing the third stage Wedum[1] states:

> ...improved accident prevention measures must originate primarily with the man who is working at the laboratory bench, in the animal room and in the laboratory kitchen. This is true in any high-risk operation regardless of whether the laboratory work is with infectious organisms, toxic chemicals or radioactive substances. Why is this? It is because in the first and second stages we have already put into use all the standardized safety techniques and standardized apparatus, and all the additional precautions that the central safety organization could devise. Nevertheless, accidents and disabling injuries will continue to occur. This is a particularly difficult situation in an infectious disease laboratory because in two-thirds of the laboratory-acquired infections, there is no definite act or accident associated with the infection, and how it was acquired is unknown.

In the introduction to a chapter on devices and procedures to protect against infection in the microbiological laboratory, Chatigny[2] evaluated the current status of laboratory safety as follows:

[1]Ibid, p. 114.

[2]Chatigny, op. cit., pp. 131-132.

In the past two decades there has been a vast growth in research, teaching, and clinical laboratory work in microbiology. In spite of many advances in protective measures made during this period, laboratory-acquired infections appear to have increased at a rate nearly paralleling this growth, and the risk of acquiring infection is still a severe problem to the laboratory worker.

The existence of the problem has long been recognized and research scientists, clinicians, engineers, and many other workers have all contributed corrective measures from their own areas of special competence in a beginning of a scientific evaluation of the problem of laboratory safety.

It is time ... for the laboratory infection problem to be included in the portfolio of the industrial hygienist, to have accident data more faithfully recorded, and to have people whose primary concern is safety blend their experience and knowledge with those of the laboratory worker in a continuing and coordinated effort to evaluate and to control laboratory-acquired diseases.

III. PROCEDURE IN COLLECTING DATA

A. COLLECTION OF DATA FROM PUBLISHED AND UNPUBLISHED SOURCES

Subproblems One and Three, treated here together, deal with published information on microbiological safety and with data obrained at Fort Detrick and from other laboratories.

Data were collected in the following topical areas: (i) summaries of past accident experience; (ii) reports of accidents and infections; (iii) surveys of accidents and infections; (iv) descriptions of institutional disease epidemics; (v) evaluations of microbiological hazards; (vi) animal handling hazards; (vii) microbiological safety equipment; ard (viii) laboratory design. The information specifically sought was that which would allow a classification of laboratory accident types, hazards, and causes, and their relative importance and frequency. The wide selection of topical areas was considered important. They are all related to safe laboratory performance and should reveal potential accident causal factors by direct or indirect means. Moreover, it seemed important to develop an understanding of the over-all interacting elements in the laboratory environment that are important in accident prevention.

The prime sources of data used by the investigator were literature references and records of the Biological Laboratories.

1. Literature References

Approximately 1500 references to published technical articles, books, and pamphlets were collected and reviewed. Those that provided applicable data on microbiological safety were used and are referenced in this document. Publications that provided no accident prevention information (primarily medical reports of laboratory infections) are not referenced individually, but appropriate summaries are provided.

The most useful reference was the report of a survey on laboratory infections published by Sulkin and Pike[1] in 1951. Reports of cases of laboratory infection in other publications were assembled by the investigator and are referred to as the foreign literature survey and the U. S. literature survey.

2. Biological Laboratories Information

Accident prevention information was collected at the U.S. Army Biological Laboratories at Fort Detrick. The accident records reviewed by the investigator were those for the period 1944 through 1962, although complete records were available only for the period 1959 through 1962.

Specific records scrutinized were (i) lost-time accident and illness reports, (ii) non-lost-time accident reports, (iii) reports of inspection committees and safety inspectors, (iv) minutes of safety councils and committees, (v) written investigations of lost-time accidents and illnesses, and (vi) annual safety summaries. In addition, information on the number, sex, and occupations of exposed laboratory personnel, and the number of exposure hours worked per year was obtained from the installation personnel records.

[1] S. E. Sulkin and R. M. Pike, "Survey of Laboratory-Acquired Infections," _American Journal of Public Health_, 41, (1951) pp. 769-781.

3. Visits to Laboratories

Accident prevention information was collected during visits to laboratories. During the period January 1959 to March 1960 the investigator visited 111 microbiological laboratories in 18 countries. Pertinent data on accident causes collected during this study are included in this report.

4. Contributions from Other Laboratories

Accident data were supplied by various other laboratories. Safety Directors of two institutions supplied the investigator with unpublished accident data for analysis and use:

1) The National Institutes of Health (NIH), U.S. Public Health Service, Bethesda, Maryland.

2) The Communicable Disease Center (CDC), U.S. Public Health Service, Atlanta, Georgia.

For convenience, the initial designations of these laboratories will be used throughout this report.

B. STUDIES WITH ACCIDENT-INVOLVED AND ACCIDENT-FREE EMPLOYEES

1. Collection of Data

Justification for studying non-accident-involved people as well as accident-involved people stems from the need to determine types of behavior or personal factors that do or do not result in accidents. Specifically of interest were behavior patterns, attitudes, perceptions, or other factors that would distinguish one group from the other.

For each subject, data were collected by examination of the employment and safety records of the subject and by a planned interview with the subject. The following types of data were obtained:

1) Age, sex, pay grade or military rank, marital status, education, previous employment or professional experience, length of government service, and frequency of use of sick leave.

2) Type of safety training received and date, number, and type of lost-time injuries, or laboratory infections, number and type of minor accidents, length of time since last reported accident, statements as to cause on past accident records, and personal information contained in accident investigations and in investigation reviews.

Conduct of the subject interviews required the following preliminary steps:

1) Formulation of subject interview techniques.

2) Testing of validity and reliability of the interview techniques.

3) Selection of subjects for study.

A preliminary interview outline was first prepared. Some questions were such as would be asked of all subjects, others were specifically for accident-involved people or for accident-free people. Questions were framed and placed in an appropriate sequence to secure the best possible cooperation from the subject being interviewed. The general nature of the questions is indicated below.

1) Questions relating to age, sex, marital status, professional experience, and occupational status.

2) Questions dealing with the health of the individual.

3) Questions dealing with attitudes toward safety regulations, safety practices, supervisors, the safety organization, and safety training procedures.

4) Questions dealing with previous accident experience.

5) Questions dealing with specific details of a reported accident.

The subject interview outline was validated in two ways: first, by consultation with safety experts, and, second, by a pilot study with 11 subjects.

Draft copies of the preliminary interview outline were submitted to eleven qualified individuals in the biological safety field for their review, comments, and suggestions. Each individual was also provided with an outline of the research project. The general qualifications of this examining committee were as follows:

1) Each held or recently had held a responsible position in microbiological laboratory accident prevention.

2) All but two had had more than five years' experience in the field of laboratory safety; a majority had had more than 10 years' experience.

3) All of the individuals were college graduates; six held M.A., Ph.D., D.V.M., or M.D. degrees.

4) Eight of the individuals had published scientific articles on microbiological laboratory safety.

The reviewers were:

Dr. A. G. Wedum, Director of Industrial Health and Safety, Fort Detrick, Frederick, Maryland.

Dr. Edward J. Lazear, Safety Director, Pine Bluff Arsenal, Arkansas.

Mr. Robert L. Alg, Safety Director, Dugway Proving Ground, Utah.

Dr. George H. Connell, Research Grants Officer, Communicable Disease Center, U.S.P.H.S., Atlanta, Georgia.

Mr. James A. Johnson, Safety Officer, Communicable Disease Center, Atlanta, Georgia.

Mr. Charles S. Kambar, Safety Division, DBO, Pine Bluff Arsenal, Arkansas.

Mr. James B. Black, Safety Director, U.S. Public Health Service, Washington, D.C.

Mr. Everett Hanel, Jr., Industrial Health and Safety Division, Fort Detrick, Frederick, Maryland.

Mr. Gardner G. Gremillion, Industrial Health and Safety Division, Fort Detrick, Frederick, Maryland.

*Mr. Peter Boyle, Biological Safety Inspector, National Institutes of Health, Bethesda, Maryland.

Dr. James F. Sullivan, Safety Officer, National Animal Disease Laboratories, Ames, Iowa.

The comments and suggestions of the reviewing committee were incorporated into the final interview schedule except in instances where different reviewers had opposing views regarding certain questions.

The interview outline was further validated through a pilot study with six subjects to determine if the framing of the questions and the order in which they were asked (i) promoted rapport with the subjects, (ii) were understood without further explanation or rewording, and (iii) elicited responses that met the objectives of the study. As a result of this pilot study minor changes were made in a few questions and the question sequence was modified. Standard interview procedures as suggested in current tests on this subject were followed as closely as possible.

Reliability of the final interview schedule was established by an additional pilot study with 11 subjects in which each subject was re-interviewed one week after the original interview.

The interview studies were done during an experimental period of 6 months beginning in March 1963 and ending in August 1963, during which 33 individuals having reportable accidents were studied as soon after their accidents as possible. Following each interview another individual doing similar work and matched in other respects as closely as possible with the accident-involved individual was interviewed. However, the second interviewee must have had an accident-free record for at least 2 years prior to the time of the interview. A total of 66 cases were studied during the experimental period. The final interview outline used by the investigator is shown in Appendix A.

2. Classification of Data

The system used to classify the laboratory accident data was that recommended by the American Standards Association.[1] Some adaption and expansion of the category sets of this system were necessary to accommodate the laboratory situation. Use of the system in modified form was advantageous because the basic methods for coding and statistical development are widely used and accepted. The modification also attempted to include factors of importance from an epidemiological point of view. In the classification system used, accident cause data were categorized in five major subject areas:

1) Accident Classes

2) Accident Types

[1]American Recommended Practice for Compiling Industrial Accident Causes, Part I, "Selection of Accident Factors," New York: American Standards Association, Z16.2 - 1941.

3) Accident Agencies

4) Unsafe Conditions

5) Unsafe Acts

Recording and statistical comparison of data were facilitated by the use of keysort cards. Data from approximately 2000 lost-time and non-lost-time accidents and infections were coded and punched onto 5-inch by 8-inch McBee Keysort Cards,* Form KS 581 B. A complete outline of the classification scheme is shown in Appendix B.

*Royal McBee Corp., Athens, Ohio.

IV. CHARACTERIZATION OF MICROBIOLOGICAL LABORATORY SAFETY PROBLEMS

This chapter presents data on microbiological laboratory accidents and infections that form an essential background for understanding the safety problems and for subsequent search for accident causal factors. The material in some respects overlaps both with that concerned with the historical development of the problem in Section II and the cause analysis that begins with Section V. While admittedly voluminous, the material in this chapter provides insights into problems and points to unique situations that require solution. The three principal parts of this chapter deal with (i) laboratory accidents and infection, (ii) the laboratory environment, and (iii) laboratory techniques and procedures.

Unfortunately, no source of information on the frequency of accidents and infections among microbiological laboratory populations exists. Therefore, in order to establish a relative basis for the frequencies to be discussed below, the following typical lost-time accident rates may be noted.[1]

All industries, 1962 - 6.19 accidents per million man hours

Chemical industry, 1962 - 3.31 accidents per million man hours

Federal civilian employees, 1961 - 9.03 accidents per million man hours

Coal mining, 1961 - 35.86 accidents per million man hours.

A. LABORATORY ACCIDENTS AND INFECTIONS

1. Frequency of Lost-Time Injuries and Infections

Of prime importance in characterizing microbiological laboratory safety problems is an understanding of the frequency of occurrence of accidents and illnesses. Obviously there is little need for research in accident prevention in any area unless the extent of the human or material loss is sufficient to justify the research effort.

a. Laboratory Infections

Laboratory outbreaks of disease originating from accidental causes are summarized in Table 3. In the thirteen outbreaks uncovered, a total of 344 people were infected. In several instances, where the number of exposed people was known, from 10 to 100 per cent of the laboratory personnel were infected. It is clear from these data that it is possible for rather large segments of a specific laboratory population to become accidentally and simultaneously infected with a disease micro-organism under study.

The 1938 epidemic of brucellosis and the 19[illegible]5 outbreak of histoplasmosis are of particular interest because both occurred in college laboratories and most of those infected were students. For the brucellosis epidemic the attack rate was about 27 per cent, with a frequency rate of at least 150.0 per million man-hours. The 26 infections with histoplasmosis reported in 1964 were also students.

[1]"Accident Facts," 1963 Edition, National Safety Council, 425 N. Michigan Ave., Chicago, Ill., p. 26.

TABLE 3. LABORATORY EPIDEMICS OF INFECTIOUS DISEASE

Disease	No. of Persons Infected	Source[a]
Psittacosis	11 (57)[b]	McCoy, 1930
Brucellosis	94 (316)	Huddleson and Munger, 1940
Q fever	15 (153)	Hornibrook and Nelson, 1940
Murine typhus	6	Loffler and Mooser, 1942
Q fever	20	Robbins and Rustigan, 1946
Q fever	16	Commission on Acute Resp. Disease, 1946
Q fever	47 (142)	Huebner, 1947
Q fever	15 (75)	Phillips, 1961
Q fever	60	Phillips, 1961
Coccidioidomycosis	13	Smith, 1950
Histoplasmosis	18 (18)	Dickie and Murphy, 1955
Histoplasmosis	26 (62)	Murray and Howard, 1964
Venezuelan encephalitis	24	Slepushkin, 1959
Tularemia	5 (14)	Barbeito, et al., 1961

a. All references shown in tables are listed in the Bibliography.
b. Numbers in parentheses show the laboratory population involved if available.

Surveys of laboratory-acquired infectious disease provide material illustrating the nature of the laboratory safety problem. A number of surveys have been concerned with one specific disease; others have included information on two or more diseases.

The single-disease surveys are summarized in Table 4. These 12 publications, covering a period of approximately 70 years, report a total of 762 accidental infections among laboratory and medical personnel. From those surveys dealing with tuberculosis the attack rate, in terms of infections per 1000 man-years, varied from 4 to 161.

Surveys dealing with more than one disease yielded additional information on the frequency of laboratory infections. Data compiled by the investigator included 1135 cases occurring between 1893 and 195[illegible]. Another survey, resulting from visits to laboratories in 18 countries, reports 426 infections occurring in 102 laboratories during the period 1946 through 1959. In one European laboratory that employed approximately 100 people, complete and documented records of laboratory infections had been maintained for the years 1944 through 1959. During that period there had been 40 laboratory infections and relapses with a lost-time frequency rate

TABLE 4. SINGLE-DISEASE SURVEYS OF LABORATORY INFECTIONS

Period Covered	Disease	Number of Infections	Reference
1885-1914	Typhoid fever	50	Kisskalt, 1915
1915-1928	Typhoid fever	59	Kisskalt, 1929
-	Brucellosis	74	Meyer and Eddie, 1941
1929-1949	Tuberculosis	60	C. E. Smith, 1950
1930-1937	Tuberculosis	72	Hedvall, 1940
1933-1945	Tuberculosis	56	Morris, 1946
1939-1945	Tuberculosis	12	Lim-Yuen, 1946
1943-1944	Tuberculosis	42	Merger, 1956
1949-1955	Tuberculosis	198	Reid, 1957
1944-1956	Tularemia	62	Van Metre and Kadull, 1959
1944-1947	Brucellosis	17	Howe, et al., 1947
1944-1955	Brucellosis	60	Trever, et al., 1959

of 50.0 per million man-hours. In 1949, Sulkin and Pike[1] summarized information on 222 laboratory infections with various viral agents. An analysis by the Bureau of Labor Statistics[2] of hospital work injuries during 1953 showed that the frequency rate for infections occurring among 22,549 hospital clinical laboratory employees was 1.0, about three times that of all hospital employees.

To date the largest body of information on laboratory-acquired infectious diseases was published in 1951 by Sulkin and Pike.[3] Information on 1342 accidental infections occurring during the previous 20-year period was obtained. Since 1950, the Committee on Laboratory Infections and Accidents of the American Public Health Association, headed by Sulkin, has maintained a file of laboratory infections reported in the literature or otherwise called to their attention. A summary of

[1]S. E. Sulkin and R. M. Pike, "Viral Infections Contracted in the Laboratory," New England Journal of Medicine, 241, (1949) p. 201.

[2]"Work Injuries and Work-Injury Rates in Hospitals," U.S. Dept. Labor, Bureau Labor Statistics, Bulletin No. 1219, February 1958, p. 44.

[3]S. E. Sulkin and R. M. Pike, "Survey of Laboratory Infections," American Journal of Public Health, 41, (1951) pp. 769-781.

this file compiled in 1957 listed 2262 cases, including the original 1342 cases.[1] A more recent summary by Sulkin[2] brings the total to 2348 infections.

Table 5 is a summary of published and collected cases of laboratory infections from the multiple-disease surveys. These data represent a total of more than 5000 documented infections, although duplication of cases has not been eliminated. They illustrate that accidental infection of laboratory workers is a substantial problem.

TABLE 5. COLLECTIONS OF DATA ON LABORATORY INFECTIONS

Period Covered	Country or Place	Number of Infections	Source
1915-1928	Germany	83	Kisskalt, 1928-1929
1915-1939	Germany	398	Draese, 1939
-	U.S.	222	Sulkin and Pike, 1951
1893-1957	World Wide	1135	Literature survey, 1962
1946-1959	World Wide	426	Personal visits, 1959
1944-1959	One European Laboratory	·0	Personal visits, 1959
1953	U.S. Hospital Clinical Laboratories	4	Bureau Labor Statistics, 1958
1930-1960	U.S. Laboratories	2348	Sulkin, 1961
1930-1960	Texas Public Health Laboratory	28	Cook, 1961

Published and collected cases of laboratory infections have been used in Table 6 to estimate infection frequency rates.

However, these must be considered as having low reliability because of the difficulties encountered in detecting and collecting all instances of accidental infection. For example, Sulkin[3] estimated that his tabulation ".. represents perhaps only a modest fraction of those that have actually occurred." The rates in Table 6 range from 50.0 to 0.10 infections per million man-hours.

[1]S. E. Sulkin, R. M. Pike, E. R. Long, C. E. Smith, M. M. Sigel, and A. G. Wedum, Laboratory Infections and Accidents, in Diagnostic Procedures and Reagents, 4th ed., American Public Health Association, New York, (1963).

[2]S. E. Sulkin, "Laboratory-Acquired Infections," Bacteriological Reviews, 25, (1961) pp. 203-209.

[3]Sulkin, op. cit., 1961, p. 203.

TABLE 6. FREQUENCY RATES FOR LABORATORY INFECTIONS

Laboratory	Infection Rates Per Million Man-Hours	Source
European Laboratory, 1944-1959	50.0	Personal Communication
TB Labs., Canada (except Quebec and Manitoba)	14.0	Merger, 1957
Research institutes, 1930-1950	4.1	Sulkin and Pike, 1951
Hospital clinical labs., 1953	1.0	Bureau Labor Statistics, 1958
Public Health labs., 1930-1950	0.35	Sulkin and Pike, 1951
Hospital labs., 1930-1950	0.30	Sulkin and Pike, 1951
Biologic manufacturers, 1930-1950	0.25	Sulkin and Pike, 1951
Agricultural and veterinary schools and experimental stations, 1930-1950	0.25	Sulkin and Pike, 1951
Colleges and medical schools, 1930-1950	0.15	Sulkin and Pike, 1951
Clinical labs., 1930-1950	0.10	Sulkin and Pike, 1951

Accident records from four institutions were examined and tabulations made of the over-all infection frequencies. These are shown in Table 7. The rates varied from 1.25 to 9.06 infections per million man-hours.

TABLE 7. INFECTION RATES AT FOUR INSTITUTIONS

Institution	Period	Infection per Million Man-Hours	95 Per Cent Confidence Limits
Fort Detrick	1954-1962	9.06[a]	5.79 - 12.33
NIH	1954-1960	3.41[b]	2.16 - 4.66
PBA[c]	1955-1962	2.86	1.25 - 4.45
CDC	1959-1962	1.25	0.74 - 1.76

a. Includes non-lost-time infections
b. Includes diseases suspected of being of occupational origin but never confirmed.
c. Pine Bluff Arsenal.

b. Lost-Time Injuries

The frequency rate for lost-time injuries (not including infections) among 22,549 clinical laboratory workers during 1953 was 3.19.[1] This rate compares favorably with those calculated for injuries at four institutions and shown in Table 8.

The combined estimated injury frequency rate at the four institutions was 3.6. This figure represents injuries occurring during approximately 68,000 man-years of exposure and appears to be a reasonable estimate of the frequency of lost-time injuries sustained by laboratory workers. When compared with the laboratory infection rates for these same institutions, the injury rates vary less between institutions. A probable explanation for this is that injury hazards are more consistently present than infectious hazards because the latter are a reflection of periodic changes in the microorganisms and research techniques used.

TABLE 8. INJURY RATES AT FOUR RESEARCH INSTITUTIONS

Institution	Period	Lost-Time Injuries per Million Man-Hours[a]	95 Per Cent Confidence Limits
NIH	1955-1960	5.45	3.86 - 7.04
CDC	1959-1962	3.92	2.90 - 4.94
PEA	1955-1962	2.86	0.55 - 5.17
Fort Detrick	1954-1962	2.10	1.45 - 2.75
Estimated combined rate		3.6	

a. Laboratory infections not included.

c. Total Lost-Time Frequencies

When total lost-time accident frequencies are computed it is important to determine the relative contribution of infections and injuries to the total. Obviously if either type represented an insignificant proportion of the total rate there would be little justification for research in that area.

The Bureau of Labor Statistics[1] reported that in the hospital clinical laboratories, injuries accounted for 77.1 per cent and occupational infections for 22.9 per cent of the total lost-time accidents. Industrial-type accidents accounted for the largest number of accidents, but not for the largest amount of lost time. The severity of accidents in hospital clinical laboratories was twice that of the over-all hospital average.

[1]"Work Injuries and Work-Injury Rates in Hospitals," op. cit., p. 46.

Table 9 shows the proportion of lost-time accident frequency rates due to infections and to other injuries in various locations. For the Fort Detrick laboratories, more than three-quarters of the lost-time rate was due to laboratory infections. Where records have been maintained in individual laboratories, the frequency of occupational illnesses often exceeds that of injuries. It appears that, as attention is focused on the identification of laboratory-acquired illnesses, their proportion as compared with injuries is increased.

TABLE 9. LOST-TIME FREQUENCY RATES OF INFECTIONS AND INJURIES

Location	Per Cent of Lost-Time Accident Frequency Due To		Source
	Infections	Injuries	
Fort Detrick, 1954-1962	77.0	23.0	-
NIH, 1955-1960	12.9	87.1	Personal Communication
Hospital lab. technicians, 1953	33.3	66.6	Bureau Labor Statistics, 1958
Dept. of Health Lab., 1950-1956	24.0	76.0	Cook, 1961
Dept. of Health Lab., 1958-1960	100.0	0.0	Cook, 1961
CDC, 1959-1962	24.6	75.4	Personal Communication
PBA, 1955-1962	50.0	50.0	Personal Communication

Table 1 summarizes the Fort Detrick lost-time laboratory accident data for the years 1954 through 1962. Lost-time injuries accounted for approximately 2[illegible] per cent of the total lost-time accidents. As shown, the average frequency rate for all lost-time accidents over a 9-year period was 10.[illegible] per million man-hours.

Table 11 is a summary of the total lost-time frequency rates for laboratory accidents from several sources. The rates vary between [illegible] and 11.8 lost-time accidents per million man-hours. Shown also is the combined rate of 6.25 proposed by Wedum[1] in 1957. Wedum's rate seems entirely reasonable as an over-all estimate, provided that it is realized that in individual institutions somewhat higher or lower rates may exist, principally because of variations in that part of the total rate contributed by laboratory infections.

[1] A. G. Wedum, "Health Hazards in Laboratories and Research Areas," Safety Monographs for Colleges and Universities, No. 7, (1957) pp. 15-20, National Safety Council, 425 N. Michigan Ave., Chicago 11, Illinois.

TABLE 10. FORT DETRICK ACCIDENT FREQUENCY RATES

Year	Rates Per Million Man-Hours		
	Lost-Time Injuries	Laboratory Infections	Total Accident Rates
1954	2.23	11.59	13.81
1955	3.67	8.25	11.91
1956	3.85	8.66	12.51
1957	0.53	13.32	13.85
1958	4.04	15.50	19.55
1959	1.54	11.31	12.86
1960	1.00	1.50	2.50
1961	0.48	2.90	3.38
1962	1.58	3.16	4.73
Average 9-year values	2.10	8.47	10.57

TABLE 11. SUMMARY OF LABORATORY LOST-TIME FREQUENCY RATES

Laboratory	Rate Per Million Man-Hours	Source
Clinical Labs. in TB Hospitals, 1953	11.8	Bureau Labor Statistics, 1958
Fort Detrick, 1954-1962	10.57	
NIH, 1955-1962	8.9	Personal Communication
PBA, 1954-1962	5.7	Personal Communication
CDC, 1959-1962	5.2	Personal Communication
All hospital clinical labs., 1953	4.5	Bureau Labor Statistics, 1958
Proposed combined mechanical, chemical, and infectious rate	6.25	Wedum, 1957

2. Severity of Lost-Time Injuries and Infections

a. Measurement Methods

Three measures of accident severity are used in the present research. The first, severity rate, is defined as the number of days charged for lost-time injuries per million man-hours worked.[1] The second measure is average days charged per injury, the use of which has been proposed by the National Safety Council.[2] This statistic is obtained by dividing the severity rate by the frequency rate or by dividing the days lost by the number of lost-time injuries. The third classification is case fatality rate—the proportion of lost-time accidents resulting in death. With laboratory infections some indication of the degree of permanent disability is given.

b. Severity Based on Amount of Lost Work Time

As a base for evaluating the severity of laboratory lost-time accidents one can examine rates typical of other work situations. For 1962, the National Safety Council[3] reported that the combined severity rate for all U.S. industries was 694 days lost per million man-hours with an average of 112 days lost per accident. For hospital clinical laboratories in 1953 the accident severity was 1000 days lost per million man-hours with an average of 214 days lost per accident.[4] In contrast to these the severity rates for accidents at microbiological laboratories and research institutions appear to be lower both in terms of days lost per million man-hours and in average days lost per accident. Table 12 shows the severity rates and average days lost per accident at four institutions for periods of 4 to 8 years.

TABLE 12. SEVERITY RATES AT FOUR INSTITUTIONS

Institution	Period	Days Lost per Million Man-Hours	95% Confidence Limits	Average Days Lost per Accident	95% Confidence Limits
Fort Detrick	1956-1962	197.8	87.4-308.4	26.1	12.3-39.9
PBA	1955-1962	108.1	46.8-169.4	18.9	12[illegible]-25.4
NIH	1957-1960	43.6	28.8- 58.4	6.1	4.6- 7.5
CDC	1959-1962	32.2	22.2- 42.2	6.[illegible]	5.2- 8.2

[1]Accident Prevention Manual, 2nd Ed., National Safety Council, Chicago, Ill., ([illegible]) pp. 17-25.

[2]F. H. Simonds and J. V. Grimaldi, Safety Management, Richard D. Irvin, Inc., Homewood, Illinois, (1956) p. 208.

[3]"Accident Facts," 196[illegible] Edition, National Safety Council, 425 N. Michigan Ave., Chicago, Ill., p. 26.

[4]"Work Injuries and Work-Injury Rates in Hospitals," op. cit., p. 46.

The rates ranged from approximately 32 to 200 for the severity rate and 7 to 26 for days lost per accident. However, the year-to-year variation at each institution was quite large, as reflected by the 95 per cent confidence limits of the yearly rates.

The contribution of infections to the over-all severity rate may vary according to the nature of the disease and the efficiency of medical diagnosis and treatment. Table 13, taken mostly from published sources, shows a substantial variation between specific diseases and different judgment criteria. With tularemia, for example, the average length of medical symptoms greatly exceeds the duration of pneumonia or fever. Obviously, the medical decision as to when the patient returns to work can greatly influence severity rates.

TABLE 13. DAYS LOST PER LABORATORY INFECTION

Number of Infections	Type of Infection	Days Lost per Infection: Mean	Days Lost per Infection: 95% Confidence Limits	Data Source
344	TB[a]	1284	-	Bureau Labor Statistics, 1958
22	TB	221	163-279	Personal visits
136	Viral[a]	128	-	Bureau Labor Statistics, 1958
43	Tularemia[b]	102	47-157	Van Metre and Kadull, 1959
11	Misc. Diseases	74	39-109	Personal visits
139	Misc. Diseases	47	37- 57	Foreign literature survey
316	Misc. Diseases	44	38- 50	World literature survey
17	Brucellosis[c]	41	32- 50	Howe et al., 1947
11	Tularemia[d]	26	21- 31	Van Metre and Kadull, 1959
26	Misc. Diseases	12	4- 19	Cook, 1961
42	Tularemia[e]	11	9- 14	Van Metre and Kadull, 1959
60	Brucellosis,[c] acute, recovered	63	-	Imboden et al., 1959
60	Brucellosis,[c] chronic, recovered	612	-	Imboden et al., 1959
60	Brucellosis,[b] chronic, symptomatic	1620	-	Imboden et al., 1959

a. For all hospital employees, 1953.
b. Days indicate duration of symptoms.
c. Days indicate duration of illness.
d. Days indicate duration of pneumonia.
e. Days indicate duration of fever.

c. Severity Based on Accident Outcome

With infectious diseases the difficulty in medically assessing permanent disability is obvious. Such information as was uncovered on the degree of disability and the fatality rates of laboratory infections is reviewed below.

Sulkin and Pike[1] classified infections according to outcome and type of infecting microorganism. More than 90 per cent of the infected persons were judged to have completely recovered. The case fatality rates varied from 2.5 to 4.5 per cent, with the higher figure due to viral infections.

In Table 14, data from several sources on the outcome of laboratory infections are compared.

Seventy per cent or more were classified as resulting in no permanent disability except for those in hospitals, reported by the Bureau of Labor Statistics, where only 31.3 per cent of 504 infected persons completely recovered. Most of those were tuberculosis infections, which were classified as permanent partial disabilities.

Particular note is made of the severity of laboratory brucellosis. In 1959, a review of 60 cases of laboratory-acquired brucellosis[2] revealed that in 22 instances (37 per cent) there was a recurrence of acute illness. In some of the patients, the illness recurred after absence of symptoms for as long as 11 months. Forty per cent of the individuals developed chronic brucellosis.[3] Sixteen individuals developed symptoms of depression, fatigue, sexual impotence, and a variety of vague aches and pains.[4] Those laboratory workers who had an acute illness followed by complete recovery had an average illness of 63 days. The chronic cases were divided into two groups whose mean duration of illness was as follows:

Number of Cases	Diagnosis	Mean Duration of Illness
6	Chronic brucellosis, recovered	1.7 years
10	Chronic brucellosis, symptomatic	4.5 years[a/]

a. Up to the time of the study.

[1]Sulkin and Pike, op. cit., pp. 772-773.

[2]R. W. Trever, L. E. Cluff, R. N. Peeler, and I. L. Bennett, Jr., "Brucellosis, I. Laboratory-Acquired Infection," Archives of Internal Medicine, 103, (1959) pp. 381-397.

[3]J. B. Imboden, A. Canter, L. E. Cluff, and R. W. Trever, "Brucellosis, III. Psychologic Aspects of Delayed Convalescence," Archives of Internal Medicine, 103, (1959) pp. 406-414.

[4]L. E. Cluff, R. W. Trever, J. B. Imboden, and A. Canter, "Brucellosis, II. Medical Aspects of Delayed Convalescence," Archives of Internal Medicine, 103, (1959) pp. 398-405.

TABLE 14. OUTCOME OF LABORATORY INFECTIONS

Complete Recovery or No Permanent Disability		Severe or Chronic or Permanent Disabilities		Deaths		Data Source
Number	Per Cent	Number	Per Cent	Number	Per Cent	
682	70.0	236	24.2	56	5.8	Literature survey
1244	92.7	59	4.4	39	2.9	Sulkin and Pike, 1951
158	31.3	338[a]	67.1[a]	8	1.6	Bureau Labor Statistics, 1958
327	84.3	56	15.2	2	0.5	Fort Detrick, 1944-1962

a. TB infections classified as resulting in permanent disability.

Thus it is apparent that laboratory-acquired brucellosis frequently results in serious long-term illness that can produce significant personality changes in infected individuals.

Infection of persons handling monkeys with monkey B virus likewise presents an unusual situation that deserves special consideration. This disease was first identified in 1934 when a physician, engaged in research with monkeys, died after having been bitten by an apparently normal *Macaca rhesus* monkey.[1] Seventeen additional human cases have since been reported.[2] Only two individuals have survived and in one of these the patient was left with severe brain damage.

Table 15 shows the fatality rates from laboratory infections. The per cent of infections resulting in death varied from less than 1 to 7.5. For comparison, the combined death rate for all disabling injuries for 1962 was 1.0 per cent.[3] The class of accidents resulting in the highest death rate was motor vehicle accidents, with a rate of 2.7 per cent. The estimated combined case fatality rate from Table 15 is 4.0.

It is clear that case fatality rates for laboratory infections may be at least as high, or higher, than the rates in other accident situations. Moreover, by comparing the death rates from laboratory infections over three time intervals, as assembled by the American Public Health Association's Committee on Laboratory Infections, there is a suggestion of a rising death rate:

[1]A. G. Sabin and A. M. Wright, "Acute Ascending Myelitis Following a Monkey Bite with the Isolation of a Virus Capable of Reproducing the Disease," *Journal of Experimental Medicine*, 59, (1934) pp. 115-135.

[2]F. M. Love and E. Jungherr, "Occupational Infection with Virus B of Monkeys," *Journal of American Medical Association*, 179, (1962) pp. 804-806.

[3]"Accident Facts," 1963 ed., National Safety Council, 425 N. Michigan Ave., Chicago, Ill., p. 3.

Period	Infections	Deaths	Case Fatality Rate
1930-1950	1342	29	2.9%
1930-1957	2262	91	4.0%
1930-1961	2348	107	4.6%

TABLE 15. FATALITY RATES FOR LABORATORY INFECTIONS

Infections	Deaths	Geographical Area	Fatality Rate, per cent	Source
442	33	Foreign countries	7.47	Survey of literature
1156	57	U.S. and Foreign	4.93	Survey of literature
2348	107	U.S.	4.56	Sulkin, 1961
426	17	U.S. and Foreign	4.00	Personal visits
26	1	Texas	3.85	Cook, 1961
1342	39	U.S.	3.00	Sulkin and Pike, 1951
504	8	U.S. Hospital Personnel	1.60	Bureau Labor Statistics, 1958
385	2	Fort Detrick	0.52	

Estimated combined case fatality rate = 4.0

3. Frequency of Non-Lost-Time Accidents

It is well known that for every lost-time or fatal accident there occur many accidents not resulting in loss of time.[1] Over-all ratios of lost-time to non-lost-time accidents probably are of little use in prevention activities. But the ratios determined in specified work locations, in certain time intervals, and with specific types of accidents may be of value in evaluating related hazards. Obviously the more frequent occurrence of non-lost-time accidents provides larger numbers for statistical treatment. On the other hand, the reliability of reporting of minor accidents will always be less than that for accidents with severe outcomes.

Table 16 shows the relative number and per cent of non-lost-time and lost-time accidents at four institutions. The ratios vary from 1:5 to 1:22.

[1] H. W. Heinrich, Industrial Accident Prevention, New York: McGraw-Hill Book Co., Inc., 3rd ed., (1950) p. 24.

TABLE 16. RELATIONSHIP OF LOST-TIME AND NON-LOST-TIME LABORATORY ACCIDENTS

Data Source	Lost-Time Accidents		Non-Lost-Time Accidents		Ratios
	Number	Per Cent	Number	Per Cent	
Fort Detrick, 1954-1962	531	15.9	2799	84.1	1:5
NIH, 1956-1960	361	6.0	5682	94.0	1:15
CDC, 1959-1962	67	11.2	530	88.8	1:8
PBA, 1955-1962	32	4.4	687	95.6	1:22
Totals	991	9.3	9698	90.7	1:10

The frequency rates of non-lost-time laboratory accidents from the same four institutions are shown in Table 17.

TABLE 17. NON-LOST-TIME FREQUENCY RATES

Institution	Period	Non-Lost-Time Injuries per Million Man-Hours	95 Per Cent Confidence Limits
Fort Detrick	1954-1962	156	141-171
PBA	1954-1962	132	95-169
NIH	1954-1960	108	100-116
CDC	1959-1962	39	30- 48

Estimated combined frequency rate = 109

The frequency of non-lost-time accidents at Fort Detrick was about four times that at CDC and 1.5 times that at NIH. This can be an accurate reflection of relative hazards or it could result from different efficiencies in reporting minor accidents. The estimated combined frequency rate for the data in Table 17 is 109.

4. Accidents and Infections in Relation to Occupation

Characterization of the microbiological laboratory safety problem according to the occupation of accident-involved people is justified if resulting analyses provide information on the relative risks of different types of work. Although a long list of laboratory occupations is possible, classification in the categories shown below made data from different sources comparable:

1) Trained scientific personnel

2) Laboratory technical assistants

3) Animal caretakers

4) Laboratory dishwashers

5) Janitors and laborers

6) Administrative and clerical personnel

7) Maintenance personnel

8) Students

9) Visitors, friends, miscellaneous

A factor of importance in classifying accidents according to occupations is an estimate of the total number of people employed in each category. By observation, one would expect laboratory technical assistants to constitute the largest single group of employed laboratory people. The distribution of the Fort Detrick population during the period of this study was:

Laboratory technical assistants	42.9%
Trained scientific personnel	36.5%
Animal caretakers	16.5%
Laboratory workers	1.2%
Others	2.9%

It was not possible to arrive at a realistic estimate of maintenance personnel at risk in the laboratories because this group consisted of persons employed outside of the laboratory buildings who entered in unknown numbers and at irregular intervals to do repair and maintenance.

Table 18 shows the per cent of the total reported accidents at three institutions that occurred to people in various occupation groups.

The majority of accidents occurred to persons directly carrying out laboratory operations. In general, technical assistants were involved in a greater number of accidents than were trained scientific personnel.

The types of laboratory personnel who had had non-lost-time accidents, lost-time accidents, or laboratory-acquired infections were distributed in the same fashion as in Table 18. At each institution technicians, animal caretakers, and dishwashers had the greatest proportion of the accidents, followed by trained scientific personnel and maintenance workers.

TABLE 18. PERSONNEL INVOLVED IN LABORATORY ACCIDENTS

Occupation	Per Cent of Accidents		
	Fort Detrick 1959-1962	CDC 1959-1962	NIH 1954-1956
Trained scientific personnel	19.9	13.5	17.9
Laboratory technical assistants	57.4	42.1	
Animal caretakers	9.0	9.9	41.1
Dishwashers, janitors, and laborers	2.5	5.9	
Administrative and clerical	0.8	7.7	7.3
Maintenance personnel	10.0	11.2	17.3
Visitors and friends, misc.	0.4	9.5	16.4
Total number of accidents	1218	555	3821

Further information was developed by limiting the comparisons by occupation to instances of laboratory-acquired infections. Comparative data from several sources are shown in Table 19. The data compare favorably with regard to the involvement of direct laboratory people: a large majority of infected persons are those whose occupations involved the direct manipulation of cultures and apparatus in the laboratory. Trained scientific personnel, technical assistants, and research students, whose jobs involve the most intimate contact with infectious agents, have by far the largest number of infections. This group, as previously shown, constitutes the largest number of at-risk people. Others who work in the laboratory such as animal caretakers, dishwashers, and janitors are involved in fewer infections.

The Fort Detrick data do not reflect the involvement of students because they are not employed at this institution. Research students in the Sulkin and Pike survey were included among the trained scientific personnel. However, in the literature survey it was possible to obtain independent estimates of student involvement. Students were involved more frequently than any other single group. It is significant that students performing research in infectious laboratories are, as a group, probably less familiar with laboratory techniques and procedures than professionals and regular technicians. They may more often be performing new or untried techniques, and may often work longer hours than other laboratory personnel.

5. Body Parts Injured By Accidents

Classification of accidentally injured body parts can be helpful in pointing to probable causal factors. For example, a high proportion of back injuries or hernias might indicate improper lifting procedures, or a large number of toe injuries might indicate a need for or a failure to use safety shoes.

TABLE 19. OCCUPATION OF PERSONNEL INVOLVED IN LABORATORY INFECTIONS

Occupation	Per Cent of Total Infections According to Data Source		
	Sulkin and Pike	Literature Review	Fort Detrick
Trained scientific personnel	78.1a/	8.4b/	58.5
Laboratory technical assistants		35.2	21.7
Animal caretakers		4.4	2.1
Dishwashers	10.3	4.4	3.8
Janitors		1.6	0.0
Students doing research	a/	41.2	
Totals	88.4	95.2	86.1
Administrative, clerical		0.4	3.7
Maintenance personnel		2.4	7.8
Visitors, friends, misc.		2.0	2.4
Totals	6.7	4.8	13.9
Students, not in research	4.9		0
Total number of infections	1286	250	369

a. Includes professional persons, research assistants, technical workers, and research students.
b. Generally includes only senior scientists and physicians.

Table 20 shows data from a Department of Labor report on work injuries in hospitals.[1] These data show that the distribution of body parts involved in hospital laboratory accidents was not the same as for accidents in other parts of the hospital. There was almost no correlation between the distributions, as indicated by a product-moment correlation coefficient of -0.15.

[1] "Work Injuries and Work-Injury Rates in Hospitals," Bulletin No. 1219, U.S. Dept. Labor, Bureau of Labor Statistics, (February 1958) pp. 48-50.

TABLE 20. BODY PARTS INJURED IN LOST-TIME LABORATORY AND HOSPITAL ACCIDENTS

Part of Body Injured	Number of Accidents in Clinical Laboratories[a]	Number of Accidents in Other Parts of Hospitals[a]
Head	21	1270
Chest	23[b]	824[b]
Back	13	2685
Abdomen	15	744
Arms	10	828
Hands	25	1646
Fingers	32	1495
Legs	14	1424
Feet	15	1648

a. Product-moment correlation coefficient, $r = -0.15$ "t" = 0.410.
b. Occupational infections classified as chest injuries.

The body parts involved in lost-time and non-lost-time accidents at Fort Detrick during a four-year period are shown in Table 21. With lost-time accidents it is evident that chest injuries are by far of greatest concern. These were almost entirely due to respiratory disease. With non-lost-time accidents, 44 per cent resulted in injury to the arms, hands, fingers, or thumbs, although there were no lost-time accidents in these categories. This result suggests that examination of non-lost-time accident records might yield poor predictive information for body-part involvement in lost-time accidents.

6. Age and Sex of Persons Involved in Accidents

Only the Fort Detrick data were detailed enough to allow analysis of the age and sex of persons having laboratory accidents. The hypothesis advanced was that the age and sex distributions of persons involved in accidents and those acquiring laboratory infections would not be different from the age and sex distributions of the total exposed population.

Table 22 shows the number of people involved in reported accidents according to age groups during a four-year period. There was little difference in the mean ages of these people and the mean age of 37.5 for the total exposed population.

In Table 23 the hypothesis that the Fort Detrick data came from sample populations with equal probabilities for each age group was tested.

At the 0.05 level of significance it was found that the age distribution for persons who had lost-time accidents or laboratory infections did not differ from the age distribution of the total exposed population. However, the age distribution of

TABLE 21. BODY PARTS INVOLVED IN LABORATORY ACCIDENTS AT FORT DETRICK, 1959-1962

Part of Body Injured	Number of Lost-Time Accidents[a]	Number of Non-Lost-Time Accidents
Head (Total)	1	137
Head and face	1	57
Eyes	0	80
Trunk (Total)	4	64
Back	3	35
Chest	37	29
Upper extremities (Total)	0	519
Arms	0	69
Hands	0	112
Fingers and thumbs	0	338
Lower extremities (Total)	4	70
Legs	2	44
Feet	1	22
Toes	1	4
Other (systemic, etc.)	0	381

a. Includes laboratory infections.

persons who had non-lost-time accidents was significantly different from that expected. The difference was due to a greater than expected frequency in the 20- to 29-year group and a less than expected frequency in the group more than 50 years old.

From an examination of personnel records at Fort Detrick it was determined that the best estimate of the sex of the total exposed population through the years and at present was 94 per cent males and 6 per cent females. Based on this estimate, analyses were made of the number of lost-time and non-lost-time accidents during the interval 1959 through 1962.

The data in Table 24 show that the sex distribution of laboratory non-lost-time accidents and all laboratory accidents was not different from the sex distribution of the exposed population.

TABLE 22. FORT DETRICK LABORATORY ACCIDENTS ACCORDING TO AGE GROUP, 1959-1962

Age Group	Number of Accident-Involved People			
	Non-Lost-Time	Lost-Time	Infections	All Accidents
20-29	364	11	10	375
30-39	656	22	21	678
40-49	373	9	8	382
> 50	107	5	4	112
Total	1500	47	43	1547
Mean ages	36.5	36.7	36.4	36.5

TABLE 23. AGE OF PERSONS INVOLVED IN LABORATORY ACCIDENTS AT FORT DETRICK, 1959-1962

Age Group	Number of Accidents					
	Non-Lost-Time		Lost-Time Injuries		Infections	
	Expected	Observed	Expected	Observed	Expected	Observed
20-29	315	364	10	11	9	10
30-39	675	656	21	22	19	21
40-49	375	373	12	9	11	8
> 50	135	107	4	5	4	4
Chi squares	13.975[a]		1.148[b]		1.140[b]	

a. Hypothesis of equal frequencies rejected at the 0.05 level of significance.
b. Hypothesis of equal frequencies accepted at the 0.05 level of significance.

No lost-time injuries or infections occurred to women during the test period. On the basis of the ratio of men to women, about two lost-time injuries and two infections would have been expected.

7. Temporal Relations in Accident Occurrence

Available data were used to test hypotheses concerning accident occurrence by month of the year, day of the week, and hour of the working day. The hypothesis

TABLE 24. SEX OF PERSONS INVOLVED IN LABORATORY ACCIDENTS AT FORT DETRICK, 1959-1962

Sex of Persons	Number of Involved People			
	Non-Lost-Time Accidents		Total Accidents	
	Expected	Observed	Expected	Observed
Male	1680	1707	1724	1754
Female	107	80	110	80
Chi square	7.247[a]		8.704[a]	

a. Hypothesis of equal frequencies accepted at the 0.05 level of significance.

advanced in each case was that accident frequency would be influenced by the time of accident occurrence no more than would be expected by chance.

Table 25 shows laboratory accidents and infections at Fort Detrick by month in relation to the number expected when each period was assigned an equal weight. The observed accident frequencies did not deviate from the predicted any more than would have been expected by chance at a significance level of 0.05.

The month of occurrence of accidents at CDC during a three-year period is analyzed in Table 26. As with the Fort Detrick accidents, the variations were no different from those expected by chance.

TABLE 25. MONTHS OF OCCURRENCE OF LABORATORY ACCIDENTS AT FORT DETRICK

Month	Accidents, 1959-1962		Infections, 1944-1962	
	Expected	Observed	Expected	Observed
Jan-Mar	318	320	95	106
Apr-Jun	318	345	95	83
Jul-Sep	318	315	95	97
Oct-Dec	318	292	95	94
Chi squares	4.459[a]		2.842[a]	

a. At df = 3 and at the 0.05 level of significance the hypothesis of equal frequencies is accepted.

TABLE 26. MONTHS OF OCCURRENCE OF ACCIDENTS AT CDC, 1959-1961

Month	Non-Lost-Time		Lost-Time		All Accidents	
	Expected	Observed	Expected	Observed	Expected	Observed
Jan-Mar	90.5	92	10.7	11	101.2	103
Apr-Jun	90.5	85	10.7	13	101.2	98
Jul-Sep	90.5	94	10.7	9	101.2	103
Oct-Dec	90.5	91	10.7	10	101.2	101
Chi squares	0.770[a]		0.818[a]		0.165[a]	

a. At df = 3 and at the 0.05 level of significance the hypothesis of equal frequencies is accepted.

In the same manner that equal numbers of accidents per three-month interval were predicted, it would be expected that each day of the working week would be equally weighted for accident occurrence. For the Fort Detrick data, accidents were listed by day of occurrence and compared with the expected numbers as shown in Table 27. At the 0.05 level of significance daily variations above that which would have occurred by chance were not detected.

The influence of hour of the working day on the frequency of accidents was determined in two ways. First, by comparing the number of accidents occurring before and after the lunch period, and, second, by comparing accidents occurring during

TABLE 27. DAY OF OCCURRENCE OF ACCIDENTS AT FORT DETRICK, 1959-1962

Day	Expected	Observed
Monday	235	229
Tuesday	235	263
Wednesday	235	225
Thursday	235	229
Friday	235	229
Chi square	4.221[a]	

a. Hypothesis of equal frequencies accepted at the 0.05 level of significance.

each hour of the work shift. The results are shown in Tables 28 and 29. Table 28 shows that the number of accidents occurring during the morning hours was significantly greater than the number occurring in the afternoon. Factors that might be responsible for this result are not readily apparent, but the result does suggest that the tiring of individuals as the work day progresses is not a significant factor leading to greater accident frequency in the afternoon.

Table 29 identifies the second and third work-day hours as being associated with greater than expected numbers of accidents.

TABLE 28. TIME OF OCCURRENCE OF ACCIDENTS AT FORT DETRICK, 1959-1962

Time	Number of Accidents	
	Expected	Observed
Morning	186	232
Afternoon	186	140
Chi square	22.752[a]	

a. Hypothesis of equal frequencies rejected at the 0.05 level of significance.

TABLE 29. HOUR OF OCCURRENCE OF ACCIDENTS AT FORT DETRICK, 1959-1962

Hour of Work Shift	Number of Accidents	
	Expected	Observed
1	47	40
2	47	78
3	47	84
4	47	30
5	47	22
6	47	47
7	47	55
8	47	16
Chi square	90.831[a]	

a. Hypothesis of equal frequencies rejected at the 0.05 level of significance.

8. Types of Occupationally Acquired Diseases

A consideration of the number of infectious agents handled in laboratories emphasized the variety of diseases represented and their varying infectivity, pathogenicity, and possible infection routes, with varying degrees of severity and duration.

Table 30 shows the number of laboratory infections due to bacteria, viruses, rickettsiae, fungi, and parasites from five sources.

TABLE 30. ORGANISMS RESPONSIBLE FOR LABORATORY INFECTIONS

Data Source	Infections Due To				
	Bacteria	Viruses	Rickettsiae	Fungi	Parasites
Sulkin and Pike, 1951 (A)	776	264	200	63	39
Foreign literature survey (B)	300	58	77	4	3
U.S. literature survey (C)	360	165	165	20	4
Personal visits (D)	246	65	101	14	0
Fort Detrick, 1943-1962 (E)	290	40	47	8	0

Product-moment correlation coefficients	"t" values
r (AB) = 0.99	12.160
r (AC) = 0.96	5.960
r (AD) = 0.97	6.914
r (AE) = 0.98	9.863

The majority of the infections were due to bacterial diseases; viral and rickettsial diseases accounted for about one-third of the total. Only a small portion of the infections were due to fungi or parasites. These data are in substantial agreement as to the relative frequency of the five types of infections, as shown by the correlation coefficients in Table 30.

Because bacterial, viral, and rickettsial diseases accounted for more than 95 per cent of the infections, further treatment of the data was limited to the most common diseases in these groups. In Table 31, the principal bacterial diseases are listed, together with the indicated frequencies from four sources.

The eleven diseases listed were responsible for about 90 per cent of the bacterial infections and approximately 50 per cent of all infections. Only the

TABLE 31. BACTERIAL LABORATORY INFECTIONS

Disease	Number of Infections by Data Source[a]			
	A	B	C	D
Brucellosis	224	205	87	26
Tuberculosis	153	7	3	173
Typhoid fever	58	4	105	8
Tularemia	55	85	0	14
Dysentery	31	1	10	3
Anthrax	30	25	3	0
Erysipeloid	27	13	2	0
Relapsing fever	17	0	8	0
Staphylococcus infections	16	0	6	0
Diphtheria	15	4	14	12
Rat bite fever	11	3	2	0

a. A - Sulkin and Pike Survey
B - U.S. Literature Survey
C - Foreign Literature Survey
D - Personal Visits

Product-moment correlation coefficients	"t" values
r (AB) = 0.77	3.657
r (AC) = 0.51	1.779
r (AD) = 0.58	2.130

correlation coefficient for the Sulkin and Pike vs. U.S. literature survey was significant at the 0.05 level.

The order of the listing of bacterial diseases in Table 31 appears to approximate their relative importance in laboratory infections, except that special consideration should be given to tuberculosis infections. The relative numbers of tuberculosis infections listed by laboratory directors during personal discussions are much greater than the number published in the literature or reported on questionnaires.

The common infections with viral and rickettsial microorganisms are shown in Table 32. The coefficient obtained with the Sulkin and Pike vs. the foreign

TABLE 32. VIRAL AND RICKETTSIAL LABORATORY INFECTIONS

Disease	Number of Infections by Data Source[a]			
	A	B	C	D
Q fever	105	106	6	96
Hepatitis	95	10	0	3
Endemic and epidemic typhus	64	37	60	5
Psittacosis	44	31	15	25
Lymphocytic choriomeningitis	19	9	1	3
Equine encephalomyelitis	17	36	0	4
Rocky Mountain spotted fever	16	23	1	0
Yellow fever	13	0	22	0
Scrub typhus	12	0	10	0
Rift Valley fever	11	8	7	0
Newcastle disease virus	11	0	4	4
Viral lymphogranuloma	5	3	1	0
Poliomyelitis	4	2	0	0
Rickettsial pox	4	0	0	0

a. A - Sulkin and Pike Survey
B - U.S. Literature Survey
C - Foreign Literature Survey
D - Personal Visits

Product-moment correlation coefficients	"t" values
r (AB) = 0.72	3.540
r (AC) = 0.25	0.904
r (AD) = 0.69	3.270

literature survey was not significant at the 0.05 level, but significance was obtained with the other two coefficients.

It is concluded that the viral and rickettsial diseases listed in Table 32 are those of greatest importance in laboratory infections and that the order of listing is an indication of their probable relative importance. However, with viral and rickettsial diseases, several important factors have a significant bearing on such estimates. Not the least of these is the fact that new viral agents or species subtypes are constantly being identified, and different animal and insect vectors are constantly being discovered. Moreover, the impact of virus cancer agents on laboratory safety remains unevaluated.

With virus diseases, just as with tuberculosis in the bacterial diseases, it is probable that the incidence of laboratory-acquired hepatitis has been underestimated.

Fungal diseases accounted for 0.9 to 4.7 per cent of all infections in the separate data sources used above. The majority of the infections were coccidioidomycosis, a potentially severe infection for which there is no specific treatment.

Hanel[1] recently made a detailed literature study of laboratory-acquired mycotic infections that included 364 published cases. Although more than three-quarters of these were coccidioidomycosis, it was clear that the relative frequency of histoplasmosis was increasing.

In order to explore the relationship of the diseases typical of the Fort Detrick laboratories with those reported in surveys, a ranking of the frequency of occurrence of nine diseases at this institution was compared with a ranking of the same nine as they were shown in the Sulkin and Pike survey. Analysis by the rank-order correlation coefficient showed that there was a positive and significant relationship between the relative frequency of those diseases typical of the Fort Detrick laboratories and the frequency of the same nine diseases as reported by Sulkin and Pike. These data are shown in Table 33.

An obvious factor influencing assessment of disease types important in laboratory-acquired infections is the relative frequency of use of the etiological agents. Data collected by personal visits provided the basis for the comparison shown in Table 34. The number of laboratory infections for each disease reported by 102 institutions was listed opposite the number of the institutions where each etiological agent was used to a significant degree.

A positive product-moment correlation coefficient of 0.76 was obtained that was significant at the 0.05 level. This result indicates a moderate and positive association between the extent of use of infectious agents among the laboratories and the number of reported infections with each agent.

In Table 34 the ratio obtained by dividing the numbers of laboratories into the number of infections may be used as an indication of the relative hazard of laboratory work with the various agents. Multiplication of the ratio value by 100 provided measures of the relative hazard of infection with the various diseases weighted by the frequency of use. The hazard index values range from 8 to 1077. The five most hazardous diseases, on this basis and for these laboratories, were Q fever, tuberculosis, tularemia, toxoplasmosis, and psittacosis.

9. Types of Laboratories Having Infections

Considerable variation may be expected in frequency of laboratory-acquired infections according to the purpose or function of the infectious disease laboratory. For example (see Table 11, page 44) infection rates are higher in research

[1]E. Hanel, Jr., "Laboratory Acquired Mycotic Infections," in manuscript.

TABLE 33. FREQUENT DISEASE TYPES AT FORT DETRICK COMPARED WITH THOSE IN THE SULKIN AND PIKE SURVEY

Laboratory-Acquired Disease	Rank	
	Detrick Infections	Sulkin and Pike Infections
Tularemia	1	3
Brucellosis	2	1
Q fever	3	2
Anthrax	4	7
Viral equine encephalitis	5	8
Psittacosis	6	5
Dysentery	7	6
Coccidioidomycosis	8	4
Glanders	9	9

Rank order coefficient = 0.65
"t" value = 3.184

institutes and tuberculosis laboratories than in the laboratories of biologic manufacturers and agricultural, veterinary, or medical schools.

To allow examination of infection rate variations according to laboratory type, 102 laboratories visited by the investigator were classified as follows:

1) Commercial or private laboratories

2) Part of an educational institution

3) Noneducational, government, or state institutes.

Studies were made of the number of disease agents in use in each laboratory, the number of personnel at risk with infectious materials, and the reported number of infections during a 15-year period.

Noneducational, government, or state institutes used, on the average, nearly twice as many disease agents as were used in commercial laboratories. Not reflected in this analysis was comparative information on the amounts of infectious materials handled. In general, operations with infectious materials in educational institutions were on a smaller scale than in the other two types.

Table 35 shows that noneducational, government, and state institutes, although representing only about one-third of the surveyed laboratories, were

TABLE 34. COMPARISON OF FREQUENCY OF LABORATORY INFECTIONS WITH USE OF THE ETIOLOGICAL AGENT

Disease	Number of Laboratory Infections	Number of Laboratories Using Agent	Hazard Index[a]
Tuberculosis	174	58	300
Q fever	97	9	1077
Brucellosis	26	20	130
Psittacosis	25	10	250
Tularemia	15	5	300
Diphtheria	12	21	57
Toxoplasmosis	11	4	275
Typhoid fever	8	19	42
Vaccinia	6	10	60
ECHO virus infections	5	14	36
Typhus fever	5	9	56
Russian spring-summer encephalitis	4	8	50
B-virus infections	4	1	25
Newcastle disease virus infection	4	3	133
Coccidioidomycosis	3	2	150
Streptococcus infections	3	12	25
Hepatitis	3	3	100
Dysentery	3	4	75
Choriomeningitis	3	2	150
Salmonellosis	3	29	10
Influenza	2	5	40
Smallpox	2	4	50
Venezuelan equine encephalitis	2	3	67
Plague	1	2	50
Mumps	1	3	33
Herpes	1	3	33
Trachoma	1	1	100
Whooping cough	1	1	100
Tetanus	1	13	8

Product-moment correlation coefficient = 0.76
"t" value = 6.059

a. Hazard Index = $\frac{\text{Infections}}{\text{Laboratories}} \times 100$

responsible for 64 per cent of the laboratory-acquired infections. Moreover, a greater percentage of these laboratories had had infections. As the last two columns illustrate, the relative number of infections per laboratory was higher for the government and state institutes than for educational or privately owned laboratories.

TABLE 35. INFECTIONS ACCORDING TO TYPE OF LABORATORY

Laboratory Classification	Per Cent of Total Laboratories	Per Cent Having Laboratory Infections	Per Cent of Total Number of Infections	Infections per Laboratory	
				1[a]	2[b]
Educational institution	44	53	25	2.28	4.29
Noneducational, government, or state institute	35	75	64	7.22	9.63
Private or commercial	21	62	11	2.19	3.53

a. Based on total number of laboratories in each category.
b. Based on number of laboratories in each category that had listed infections.

These findings were clarified, in part, by an accounting of the relative number of persons employed and those at risk. Although only slightly more than one-third of the laboratories were noneducational, government, or state institutes, these accounted for more than one-half of the total number of laboratory employees as well as for more than one-half of those that were at risk.

Analysis of the above data, as shown in Table 36, allowed rejection of the hypothesis of infection rates equal to those expected.

TABLE 36. INFECTIONS IN RELATION TO AT RISK EMPLOYEES

Type of Laboratory	Infections		
	Expected[a]	Observed	Chi Square
Educational institution	72.4	106	
Noneducational, government, or state institute	234.3	273	
Private or commercial	119.3	4[illegible]	65.802[b]

a. Based on relative number of employees at risk.
b. At df = 2 and at 0.05 level of significance, hypothesis of equal frequencies is rejected.

In relation to the number of employees at risk with infectious agents, private and commercial laboratories had less than one-half of the number of infections expected. Noneducational and educational institutes had 16 and 47 per cent more infections than expected respectively. These data allow a comparison of reported rates on the basis of the type of laboratory and the estimated number who were at risk in each type of laboratory. Chi square analysis allowed rejection of an hypothesis of equal attack rates. The largest differences in expected and observed infection frequencies occurred in research institutes and in colleges and medical schools. For the former the observed frequency was 8.3 times that expected on the basis of equal attack rates; for the latter, the observed frequency was only 56 per cent of that expected.

It is concluded that the highest rates of work-acquired infections may be expected in research laboratories. Moreover, it is clear that the number of infectious agents in use in a laboratory, and the relative number of at-risk employees, may affect infection rates in different ways according to the type of laboratory in question. In general, noneducational, government, or state institutes use a greater variety of infectious agents, have larger numbers of potentially exposed personnel, and show the highest frequency of infections. On the basis of number of potentially exposed people, infection rates are higher than might be expected in private or commercial laboratories.

It is predictable that, unless there is aggressive medical diagnosis in support of a laboratory safety program, the true frequency of accidental infections will not be known. Even when there is such a program, there exists the danger of underestimation of infection frequency because of (i) misdiagnosis, (ii) unreported infections, and (iii) infections mistakenly ascribed to non-occupational categories.

A tabulation, based on the Sulkin and Pike data, of the estimated incidence of laboratory infections in various types of U.S. laboratories is shown in Table 37.

Table 37 emphasizes the necessity of obtaining information on all infections occurring in the laboratory for analysis when studying accident causes. Therefore the hypothesis was advanced that inapparent infections constitute a significant portion of the total number of laboratory infections.

The relative number of lost-time and non-lost-time diseases at three institutions is shown in Table 38. A significant proportion of the laboratory infections showed no symptoms severe enough to cause loss of work time.

B. LABORATORY ENVIRONMENT IN RELATION TO ACCIDENTS AND INFECTIONS

Approximately 175 million dollars per year is spent in this country for the construction and remodeling of biomedical research facilities.[1] The magnitude of this investment suggests the importance of assuring the adequacy of the safety measures in these facilities. To this end several recent architectural and planning guides for medical research facilities give specific recommendations relating to special design standards for laboratories.[2,3]

[1] D. L. Snow, "Principles of Space Planning for Biomedical Research Laboratories," National Institutes of Health, Division of Research Services, Bethesda 14, Md., (1962) p. iii.

[2] "Medical School Facilities, Planning Consideration and Architectural Guide," U.S. Public Health Service Publication 875, (1961) pp. 112-118.

[3] "Planning and Design of Medical Research Facilities," National Institutes of Health, Division of Research Services, Bethesda 14, Md., (1962) pp. 6-10.

TABLE 37. LABORATORY INFECTIONS IN VARIOUS TYPES OF LABORATORIES

Type of Laboratory	Estimated Avg. No. of Persons At Risk Annually	No. of Infections Recorded in 20 Years	Expected Infections[a]	Attack Rate Per Year Per 1000
Research institutes	2,948	267	32	4.1
Public Health laboratories	12,157	169	135	0.7
Hospital laboratories	36,212	428	399	0.6
Biologic manufacturers	5,022	54	56	0.5
Agricultural and veterinary schools and exp. stations	10,145	94	112	0.5
Colleges and medical schools	45,641	281	503	0.3
Clinical laboratories	8,788	41	97	0.2
Total	120,913	1334	1334	0.5

a. Based on assumption of equal attack rates.

TABLE 38. LOST-TIME AND NON-LOST-TIME DISEASES AT THREE INSTITUTIONS

Data Source	Non-Lost-Time Diseases		Lost-Time Diseases	
	Number	Per Cent	Number	Per Cent
Fort Detrick, 1944-1962	52[a]	17.1	252	82.9
NIH, 1954-1960	195[b]	77.7	56	22.3
CDC, 1959-1962	5	33.3	10	66.7

a. Serologically confirmed.
b. Diseases suspected of being of occupational origin, including infectious and noninfectious diseases, allergies, etc., usually not serologically or medically confirmed.

The facilities provided for infectious laboratories have an important relationship to microbiological safety. Good design features for buildings and rooms can be valuable in containing and controlling infectious agents. If a building is not properly designed, its features can complicate or limit efforts to minimize risks of accidents and infections. Instances of laboratory epidemics cited previously are examples of how airborne contaminants may spread from one room to other areas throughout the building. In the previous Section, factors characterizing the microbiological laboratory safety problem were examined. Following the principles of epidemiological research, it next is important to examine the physical environment in which accidents and infections occur. Because up to 80 per cent of the lost-time laboratory accidents may be due to occupationally acquired diseases, containment of infectious agents is one of the principal problems in laboratory safety. It follows, therefore, that building features and laboratory equipment that hinder or help containment will have a direct effect on accident causation.

In this Section a number of laboratory environment factors will be considered, ranging from the age and size of the laboratory facility to types of specific safety equipment provided. The aim is to show how these environmental factors are related to accidents and infections.

1. Age of Laboratory Buildings

While the age of a laboratory facility is not necessarily a criterion for judging its adequacy for safe manipulations of microorganisms, in certain instances it can be a measure of the probable extent to which the facilities assist or hamper safe performance. The average age of 142 laboratory buildings, mentioned in publications or visited by the investigator, was 19 years. About 10 per cent of the buildings were more than 55 years old and the oldest building in use was 90 years old.

To allow testing of the hypothesis that the age of the laboratory buildings was not related to the adequacy of the safety programs carried on within them, a rating system was constructed in which each of 85 laboratories was given a numerical score up to 100 points. Points for each laboratory's score were assigned according to the following schedule:

Safety Feature	Points Assigned
Had written safety regulations	10
Used an accident reporting system	10
Had an appointed safety officer	10
Conducted safety training programs	10
Had safety committees	10
Vaccinated personnel	10
Had had no laboratory illnesses	10
Used ventilated cabinets	10
Used ventilated animal cage racks	10
Subjective evaluation of management's attitude toward safety	1 to 10

The range of the scores obtained was 11 to 91. Construction of a scatter diagram of these data, plotting age on the abscissa and safety program score on the ordinate, revealed, by inspection, a substantial degree of linearity for buildings up to age 62. The five buildings older than 62 years were either 89 or 90 years old and tended to score higher than would have been expected on a linear relationship. Since four of the five buildings had received extensive renovations, which tended to improve their program scores, these older buildings were not included in the subsequent analysis.

The building ages and safety program scores are shown in Table 39. A product-moment correlation coefficient of -0.81 was obtained. The significance of this figure was evaluated by a "t" test at df = 78 wherein a value of 12.320 allowed rejection of the hypothesis of zero correlation at greater than the 0.01 level of significance. Thus it appears that the age of these laboratory buildings to a moderately high degree was associated with the adequacy of the safety program carried on within them. As the age of the buildings increased there was a significant lowering of the safety program scores. Although this result, in itself, does not allow a positive statement of causal relationship, it is apparent that the better laboratory safety programs tended to be located within the more recently constructed buildings.

2. Costs of Construction

As with building age, construction and maintenance costs are not a direct criterion for safety. However, the magnitude of the costs illustrate a possible problem in the engineering approach to laboratory safety. This is a problem possibly facing many laboratory directors. How can the director convince administrative officials that constructing and equipping an infectious disease laboratory with suitable safety features justifies an expenditure per square foot much higher than for some other types of construction?

A U.S. Public Health Service publication[1] estimated (1961) the average cost of medical education facilities, partly equipped, to be approximately $30 per square foot with a range of $22 to $45. Recent biological research laboratories with installed equipment, including stainless steel safety cabinet systems, have cost from $98 to $179 per square foot.[2]

Table 40 shows some representative cost data collected by the investigator. The cost per square foot for new laboratories in most cases was higher than is usually expected for non-laboratory structures ($15 to $20 per square foot). These cost data illustrate that high construction costs can be a factor in limiting the full application of the engineering approach to achieving safe working conditions.

3. Space Relationships

Inadequate per capita space within laboratories could contribute to increased work risks. The amount of space available to persons in the Fort Detrick laboratories was determined and compared with the per capita space in 32 laboratories not having student facilities and in 14 laboratories with student facilities.

Table 41 shows the per capita space available in typical Fort Detrick laboratories. The average space per person for all laboratories was 600 square feet.

Space relationships in other laboratories are shown in Tables 42 and 43.

The average amount of space available in the 32 non-teaching institutions was close to the Fort Detrick average. However, direct comparisons were difficult because the Fort Detrick data did not include hallways that are included in Tables 42 and 43.

[1]"Medical School Facilities, Planning Considerations and Architectural Guide," op. cit., p. 122.

[2]A. G. Wedum and G. B. Phillips, "Criteria for Design of a Microbiological Research Laboratory," American Society of Heating, Refrigerating, and Air-Conditioning, 6, (1964) pp. 46-52.

TABLE 39. AGE AND SAFETY PROGRAM SCORES FOR 80 LABORATORIES

Building Age, years	Score	Building Age, years	Score	Building Age, years	Score
1	75	4	60	29	28
1	64	4	67	30	42
1	88	5	80	30	33
1	88	5	57	30	46
1	78	5	46	30	33
1	55	5	46	30	26
1	59	5	60	30	30
1	78	5	52	39	18
2	67	5	68	40	23
2	59	7	56	40	23
2	73	7	44	40	22
2	75	8	46	40	11
2	40	8	36	41	25
2	38	8	65	46	12
2	66	10	54	49	22
2	58	10	68	50	27
2	60	10	38	50	13
2	80	13	57	50	12
2	77	16	45	50	20
2	69	16	44	54	30
3	79	19	34	58	34
3	74	20	54	58	22
3	91	21	30	58	24
3	46	24	55	62	18
3	33	24	33		
3	65	24	26		
3	58	24	30	$r = -0.81$	
4	70	25	30	"t" = 12.320	

Data from Table 42 were used to examine possible relationships between space per person provided in 32 laboratory institutions and the adequacy of the safety program or the relative number of infections occurring within each facility. For each laboratory a numerical rating of the safety program was made based on the scoring system previously described. In addition, for each laboratory, the average number of reported infections per 1000 man-years was listed. These data are shown in Table 44.

TABLE 40. COST DATA FOR LABORATORY CONSTRUCTION

Country	Square Feet of Floor Space	Cost per Square Foot Without Equipment	Cost per Square Foot With Equipment
U.S.	28,000	$26	$53
Australia	150,000	21	-
Finland	120,000	14	-
Sweden	45,000	44	55
Sweden	40,000	50	70
England	75,000	28	-
England	18,000	-	85
Norway	37,450	20	23
Norway	2,500	-	14

TABLE 41. SPACE UTILIZATION IN FORT DETRICK LABORATORIES

Type of Laboratory	Average Square Feet per Person[a]	95% Confidence Limits
Virus research	853	424 - 1282
Bacteria processing	617	452 - 782
Medical bacteriology	515	423 - 607
Aerosol research	390	321 - 459
All laboratories	600	200 - 1100

a. Figures do not include hallways, conference rooms, and utility areas.

Scatter diagrams of the per capita figures and scores, and of the per capita figures and infections failed to show that any useful relationships existed. Product-moment correlation coefficients were also calculated. At df = 30 neither correlation was significantly different from zero at the 0.05 level. Therefore, among this sample of laboratories, there was insufficient evidence to show that the amount of working space per person was related to safety in terms of infection rates or in terms of the safety program scores.

TABLE 42. SPACE RELATIONSHIPS IN 32 LABORATORIES

Floor Area, square feet per person	Per Cent
Less than 100	6
101 to 500	53
501 to 1000	28
1001 to 2000	13
Average floor area per person - 608 square feet	

TABLE 43. SPACE RELATIONSHIPS IN 14 LABORATORIES IN WHICH STUDENTS WERE ACCOMMODATED[a]

Floor Area, square feet per person	Per Cent
200 to 500	43
501 to 1000	43
1001 to 2000	14
Average floor area per person - 728 square feet	

a. Students not included in calculations.

Based on the data given in Table 44, it is concluded that, although crowding may be a hazard-producing problem in some particular laboratories, it does not seem to be a general problem.

Because animals are commonly used in biomedical research it was of interest to examine the relative amount of laboratory space used for housing them. Obviously the frequency of use of animals may be related to the frequency of accidental bites received by handlers and to the level of risk of acquiring diseases from infected animals. To provide a basis for examination of these factors, data on the amount of research space in a number of research institutions was abstracted from a report by the National Research Council.[1] As shown in Table 45, medical research

[1]"Animal Facilities in Medical Research," ILAR Report, National Research Council, Washington, D.C., (May 1962) pp. 35-36.

TABLE 44. SPACE PER CAPITA IN 32 LABORATORIES COMPARED WITH SAFETY PROGRAM SCORES AND INFECTIONS

Square Feet per Person A	Safety Program Score B	Infections per 1000 Man-Years C
80	78	0
180	45	5.0
200	57	0.3
235	24	23.4
266	56	0
270	88	0
300	57	7.4
350	58	66.7
375	56	0
380	23	0
385	34	0.8
400	12	1.0
400	44	24.0
416	35	8.3
433	34	0.7
450	78	6.0
500	23	0
500	13	40.0
500	12	4.0
500	57	6.3
600	44	2.0
715	23	0
750	23	5.0
750	34	2.5
750	13	0
1000	43	4.0
1000	34	11.1
1000	13	20.0
1500	56	30.0
1500	44	3.3
1600	14	20.0
1600	55	13.3

r (AB) = -0.22, "t" = 1.269
r (AC) = 0.15, "t" = 0.838

institutions reported that from 15 to 57 per cent of their research space was used for animals. The ratios of research space to animal space varied between 5:1 and 1:1.

From these data it is concluded that that part of the laboratory environment used for animal experimentation is a significant portion of the whole and should be considered in an investigation of laboratory accident causal factors.

TABLE 45. SPACE USED FOR ANIMAL HOUSING IN 56 INSTITUTIONS

Type of Institution	Ratio of Research Space to Animal Space	Per Cent of Space Used for Animals
Veterinary schools	1:1	56.8
Private laboratories	2:1	33.6
Research hospitals	4:1	24.2
Medical and dental schools	5:1	15.1

4. Animal Utilization

Because the use of research animals accounts for a significant portion of the functional laboratory space, additional data were gathered to allow a more exact characterization of the problem of animal room safety. In regard to laboratory infections, it has been estimated that 30 to 40 per cent are in some way connected with the handling of infected animals or their tissues.[1]

In the institutional survey conducted by the investigator, 92 of 102 infectious disease laboratories (90 per cent) used animals. A survey by the National Research Council[2] showed that about 79 per cent of the U.S. laboratory animal consumption was due to research procedures, 18 per cent to teaching uses, and 3 per cent to use in diagnostic tests or biologics production. Among 56 laboratory institutions, those classified as private laboratories used an average of almost 200,000 animals per year per institution; medical and dental schools used annually about 50,000 animals each. Research hospitals and veterinary schools averaged 10,000 to 12,000 animals per year. The laboratory mouse was the most frequently used animal species (68 per cent), followed by rats, rabbits, and guinea pigs. Monkeys and other primates, which are of particular interest because of the severity and frequency of the bites to handlers, accounted for less than one per cent of the total number of animals.

Examination of the Fort Detrick data on research animal utilization for the years 1951 through 1962 revealed a steady increase in the number of animals used.

[1] G. B. Phillips and J. V. Jemski, "Biological Safety in the Animal Laboratory," Laboratory Animal Care, 13, (1936) pp. 13-20.

[2] ILAR Report, op. cit., pp. 30-34.

When utilization was separated by animal species it was shown that the increases were mainly due to an increased use of mice and monkeys.

However, to establish a realistic animal-use measurement, the number of all species of animals used per year per 1000 man-hours of laboratory exposure was determined. These weighted data, shown in Table 46, show that the potential hazards of accidents involving animals have increased considerably because of increased animal utilization.

TABLE 46. ANIMAL UTILIZATION PER 1000 MAN-HOURS OF EXPOSURE AT FORT DETRICK

Year	Animals[a] Used Per 1000 Laboratory Exposure Hours
1954	144
1955	158
1956	229
1957	299
1958	358
1959	301
1960	358
1961	419
1962	460

a. Includes only mice, guinea pigs, and monkeys.

5. Building Design Features

In addition to the problem of construction costs, failure of administrators to make certain policy decisions prior to beginning the design of a new laboratory is frequently the reason for subsequent deficiencies in safe facilities.[1] Typical of the required policy decisions are the following:

1) What infectious organisms and what types of experiments are contemplated?

2) What volume of infectious material is anticipated?

[1]G. B. Phillips, "Programming for Infectious Disease Animal Facilities," presented at the Symposium on Research Animal Housing sponsored by the National Research Council, Washington, D.C., November 16-17, 1962.

3) How many people will work in the facility and under what conditions of supervision?

4) What risk level for injuries and infections is management willing to accept?

5) What are the legal aspects of requirements for safety and containment?

Table 47 lists the frequency of a number of safety features present in 102 laboratories.

TABLE 47. SAFETY FEATURES IN 102 LABORATORIES

Safety Feature	Per Cent of Laboratories Having Feature
Air filtered, inlet	24
Air filtered, outlet	15
Air treated with ultraviolet, inlet	13
Air treated with ultraviolet, outlet	6
Air balanced, positive in laboratories	21
Air balanced, negative in laboratories	19
Change rooms	23
Cubicles for isolation of work	46
Sewage treatment systems	13
Ultraviolet lamps	73
Ventilation systems	60

According to strict criteria, only five of the laboratories were considered to be entirely adequate and up-to-date in the field of microbiological safety. Only 60 per cent of the buildings had ventilation systems. Even when laboratory rooms were ventilated, the animal quarters frequently were not. Treatment by filtration of air entering laboratories was more frequent than treatment of potentially contaminated exhaust air. More laboratories were maintained at a positive pressure than at a negative pressure. There seemed to be a general feeling in virus laboratories that inlet air filtration and positive balance are necessary to carry out manipulations without contamination.

Twenty-three per cent of the laboratories had change rooms, but a common failing was the lack of any visual or physical separation of infectious disease areas. Only 25 per cent of the laboratories had signs, change rooms, locked doors, or any other means of indicating to a student or visitor when he was entering a potentially contaminated area.

In building design, less attention was given to the infectious hazards relating to the holding and autopsy of laboratory animals than to any other phase of laboratory operations. Less budget money and less supervisory attention was given to the animal holding and autopsy areas than to the laboratory area. Indeed, autopsy and animal holding rooms were sometimes converted horse stables or coal bins. From the design features used in many laboratories, protecting the experiment appeared to be more important than protecting the personnel.

6. Safety Equipment

Three types of safety equipment usually are considered necessary for infectious disease work: (i) ventilated safety cabinets for the isolation of work procedures, (ii) isolation equipment for infected animals, and (iii) miscellaneous small safety devices. Cabinets that externalize infectious or toxic materials from laboratory workers have been described as "the most important single item ... in the control of infectious hazards."[1]

In evaluating the quality and quantity of the safety equipment provided in 102 laboratories, the investigator observed schools and universities to be less well off than government-owned or commercial laboratories.

Although most infectious disease laboratories were reasonably well equipped with essential apparatus such as microscopes, balances, and pH meters, there was a deficiency in quality and quantity of equipment for decontamination, sterilization, and personnel protection. The most important deficiency was in the type and amount of ventilated cabinets and animal cages to externalize personnel from infectious microbiological aerosols. Ventilated safety cabinets for laboratory manipulations were used in only 38 per cent of the laboratories; only about 10 per cent had cabinets of adequate design for effective personnel protection. Sixteen laboratories held infected animals in protected ventilated closures. In general, animal cages, cage racks, and equipment for animal autopsy provided little protection for workers in infectious animal quarters.

Autoclaves were frequently poor in design, insufficient in number, and not properly located. Germicidal ultraviolet was widely used but without proper regard to testing and maintenance of the lamps. Moreover, safety equipment for centrifuging, pipetting, blending, lyophilizing, or injecting animals was not always used even when it was available.

Table 48 shows a tabulation of the types of safety equipment present in 102 laboratory institutions. It is concluded that most infectious disease laboratories have the opportunity of reducing accident risks by the increased use of safety equipment.

C. TECHNIQUES AND PROCEDURES IN RELATION TO ACCIDENTS AND INFECTIONS

1. Laboratory Hazards Studies

A common method for the assessment of infectious microbiological hazards of laboratory procedures involves repeating the manipulations, using harmless

[1]A. G. Wedum, "Control of Laboratory Airborne Infection," Bacteriological Reviews, 25, (1961) p. 213.

TABLE 48. SAFETY EQUIPMENT IN 102 LABORATORIES

Type of Equipment	Per Cent of Laboratories Having the Equipment
Animal cages or cage rack, ventilated	16
Blendors, closed	7
Cabinets, ventilated	38
Centrifuge safety equipment	42
Loop incinerators	21
Pans, covered, for discard items	47
Pipette discard containers, autoclavable	29
Pipettor devices	51
Syringes, needle-locking	30

microorganisms, while taking samples of nearby surfaces and of the air. Thus estimates can be made of the degree to which infectious organisms are released to the environment of the laboratory worker. Some investigators have tested laboratory procedures with pathogens under suitable conditions of containment. Another approach has been to use susceptible animals to detect the transfer or escape of microorganisms. Such studies have usually been concerned with the degree to which an infected laboratory animal distributes infectious material to the environment; they assume that if an adjacent normal animal becomes infected there is some potential hazard to susceptible humans.

For the purpose of this study a detailed description of the reported research on laboratory procedures is not required. However, it is necessary to summarize and evaluate some research in order to provide a basis for detecting accident causal factors. In considering these data it should be emphasized that the evidence is often presumptive because of the technical difficulties in continuously monitoring the laboratory environment. To illustrate, there is no biological equivalent of the geiger counter or radiation film badge that can be used in routine surveillance to detect exposures to infectious agents. The present state of the technology usually allows only a subjective comparison of how the laboratory technique was carried out in relation to the results of safety research obtained during stimulated techniques.

In support of this research it is important to realize that with many diseases very small numbers of microbial units can initiate infection in man. This is illustrated in Table 49, which was prepared by Wedum[1] from a number of published articles. Human infection with most of the diseases listed in Table 49 can be

[1] A. G. Wedum, "Laboratory Safety in Research With Infectious Aerosols," Public Health Reports, 79, (1964) pp. 619-633.

TABLE 49. HUMAN INFECTIOUS DOSE

Microorganism of	Man Infected By	Growth Medium		Microbial Units Per Human Infectious Dose	Reference
		Medium	Microbial Units/ml		
Malaria	IV	Blood	4×10^4	10	Boyd and Kitchen, 1943
Q fever	INH	Egg yolk	1×10^{10} [b]	10 [b]	Tigertt and Beneson, 1956
Salmonellosis	O	Beef broth	1×10^9	10^6	McCullough and and Eisele, 1951
Scrub typhus	ID	Egg yolk	15×10^9 [b]	3 [b]	Ley, et al., 1952
Syphilis	ID	Rabbit testis [a]	36×10^6	57	Magnuson, et al., 1956
Tularemia	ID	Broth	1×10^{10}	10	Saslaw, et al., 1961
Tularemia	INH	Broth	1×10^{10}	10	Saslaw, et al., 1961
Venezuelan encephalitis	SC	Egg	33×10^{10} [b]	1 [b]	Smith, et al., 1956
West Nile fever	IM	Mouse brain	33×10^9 [b]	1 [b]	Southam and Moore, 1954

a. Centrifuged resuspended preparation.
b. In mouse or guinea pig infective units.

IV = intravenous, ID = intradermal, SC = subcutaneous,
IM = intramuscular, O = oral, INH = inhalation

initiated by 1 to 10 of the proper microbial units. The results of hazards studies with simulant microorganisms should be evaluated in light of the low magnitude of infectious doses.

The 1956 publication by Reitman and Wedum[1] summarizes much information on the amount of contamination released during bacteriological procedures. All of the techniques tested, when repeated a number of times, produced contamination of the

[1]M. Reitman and A. G. Wedum, "Microbiological Safety," Public Health Reports, 71, (1956) pp. 659-665.

environment. Previous publications by Anderson, et al.,[1] and Wedum[2] also show this same result. More recently Barbeito, et al.[3] investigated the hazard resulting from dropped petri dish cultures. Kruse,[4] in 1962, evaluated the hazards of laboratory procedures with a pathogenic fungus.

Table 50, adapted from a series of articles published in 1955 and 1956[5] illustrates the findings from laboratory hazards studies. Obviously the performance of laboratory manipulations is a personal matter, the results of which will vary widely among different persons and for the same person working at different times. From the above research the following manipulations and accidents are examples of those found to contribute significant amounts of infectious material to the laboratory environment.

Dropping an ampule of lyophilized culture on the floor

Breaking a tube of culture in a centrifuge

Grinding infected material in a Waring blendor

Pouring cultures into a flask

Removing culture from a vaccine bottle with a syringe and needle

Inoculating animals with syringe and needles

Streaking agar plates

Harvesting allantoic fluid from infected eggs

Transfer of airborne infectious diseases from experimental to normal animals during laboratory investigations was first documented and studied in the 1940's.[6] Although many subsequent observations and studies have been made, the summary by Kirchheimer, et al.[7] in 1961 is adequate demonstration of the potential infectious

[1]R. E. Anderson, L. Stein, M. L. Moss, and N. H. Gross, "Potential Infectious Hazards of Common Bacteriological Techniques," Journal of Bacteriology, 64, (1952) pp. 473-481.

[2]A. G. Wedum, "Bacteriological Safety," American Journal of Public Health, 43, (1953) pp. 1428-1437.

[3]M. S. Barbeito, R. L. Alg, and A. G. Wedum, "Infectious Bacterial Aerosol from Dropped Petri Dish Cultures," American Journal of Medical Technology, 27, (1961) pp. 318-322.

[4]R. H. Kruse, "Potential Aerogenic Laboratory Hazards of Coccidioides immitis," American Journal of Clinical Pathology, 37 (2), (1962) pp. 150-158.

[5]M. Reitman, G. B. Phillips, R. L. Alg, and E. Hanel, Jr., "Biological Hazards of Common Laboratory Techniques, I-IV," American Journal of Medical Technology, 21,22 (1955-1956) pp. 338-346, pp. 14-17.

[6]M. B. Lurie, "Prevention of Natural Air-Borne Contagion of Tuberculosis in Rabbits by Ultraviolet Irradiation," Journal of Experimental Medicine, 79, (1944) pp. 559-572.

[7]W. F. Kirchheimer, J. V. Jemski, and G. B. Phillips, "Cross-Infection Among Experimental Animals by Organisms Infectious for Man," Proceedings of the Animal Care Panel, 11 (1961) pp. 83-92.

TABLE 50. AEROSOLS FROM COMMON LABORATORY PROCEDURES

Technique	Average Number of Clumps of Organisms Recovered from Air During Operation
Pipetting 10 ml culture into 1000 ml broth	2.4
Drop of culture falling 12 inches onto	
Stainless steel	49.0
Painted wood	43.0
Hand towel wet with 5 per cent phenol	4.0
Resuspending centrifuged cells with pipette	4.5
Blowing out last drop from pipette	3.8
Shattering tube during centrifuging	1183.0
Inserting hot loop into broth culture	8.7
Streaking agar plates	0.2
Withdrawing syringe and needle from vaccine bottle	16.0
Injecting 10 guinea pigs	16.0
Making dilutions with syringe and needle	2.3
Using syringe and needle for intranasal inoculation of mice	27.0
Harvesting allantoic fluid from 5 eggs	5.6

risks arising from handling infected animals. It was concluded from these studies that the frequency of cross infection with a number of disease microorganisms is sufficient to assume that a considerable hazard to the laboratory worker may often exist. Moreover, it is clear that both air and surfaces should be considered in disease transmission and that, to protect the worker, special animal isolation techniques are usually required.

Some techniques common to microbiological laboratories have not been experimentally evaluated because the hazards arising from them are obvious. The two most common techniques are (i) oral pipetting of infectious or toxic fluids and (ii) the use of syringes with non-locking needles for handling infectious cultures. In addition, accidentally inoculating oneself or a co-worker with a syringe and needle is common cause of laboratory-acquired disease.

The conclusions derived from a study of available information on the hazards of laboratory techniques are as follows:

1) Some procedures, such as mouth pipetting, are obviously hazardous and should be eliminated.

2) All laboratory manipulations of infectious microorganisms have the potential of creating unsuspected contamination of air or surfaces.

3) Infected animals can present a hazard of infection to laboratory workers.

4) Some procedures, such as the use of a syringe and needle, have inherent hazards that are controlled best by using substitute techniques when possible or by exercising extreme care when performing the procedure.

5) In all laboratory procedures a vast difference probably exists in the ability of different individuals to perform safely. These differences are not easily detected, but it can be predicted that they depend in large measure on proper individual training and motivation.

2. Typical Procedures Used in Laboratories

Observations by the investigator of the procedures used in a number of laboratories are summarized in the following paragraphs. Table 51 is a compilation of some of the practices observed in the laboratories. Other procedures were mentioned earlier in relation to safety equipment.

Among the obvious precautions that should be taken in laboratories handling infectious disease microorganisms are those pertaining to smoking, eating, and

TABLE 51. PRACTICES IN 102 LABORATORIES

Practice	Per Cent of Laboratories Allowing Practice
Oral pipetting	62
Food and drinks brought into and consumed in laboratory area	[illegible]
Smoking allowed in laboratory area	48
Complete change of clothes required (male only)	10
Change of shoes required	22
White coats worn (male only)	[illegible]
No respiratory devices used	[illegible]
Gauze masks sometimes worn	[illegible]
Effective type of respirators used	2
Upright, non-autoclavable pipette discard jars used	[illegible]

drinking. Yet in 30 per cent of the laboratories surveyed, food or drinks were consumed in the infectious areas. Smoking was allowed in 48 per cent of the laboratories. Why greater control was not exercised over these aspects of laboratory conduct is partly explained by the observation that only rarely was there a clear separation of infectious and clean areas and only occasionally was there a suitable room that could be used for smoking and coffee drinking.

The importance of safe procedures when handling infectious microorganisms was more generally recognized than was the need for special equipment and building design features. However, there was not widespread understanding of the ease with which certain procedures can create airborne contamination of the laboratory environment. Ironically, those procedures universally known to be of importance in preventing laboratory illnesses were only partially accepted. For example, the hazards of oral pipetting are well known, yet 63 per cent of the institutions permitted this procedure. Only 30 per cent used needle-locking syringes, although the hazards of spraying infectious fluids with friction-fitting needles are universally recognized.

Although procedures in some laboratories were governed by written regulations, there is need for general acceptance of adequately prepared procedural rules. Specifically needed is an adequate summation of research on hazards arising from various laboratory procedures. Also, in the development of new laboratory procedures there is a need to include aspects for personnel protection.

In general there was little evidence of adequate follow-up investigation to assess the value of those procedural changes made to improve safety. Methods of assessing microbiological hazards through the use of surface and air sampling techniques were infrequently used. Although many changes made on the basis of best judgment were probably effective in reducing infectious hazards, adequate validation of their effectiveness would increase their general value, particularly when adopted in other laboratories. A list of some specific hazardous procedures observed by the investigator is shown below.

1) Oral pipetting of infectious cultures and blowing out the last drop from a pipette.

2) Using an electric fan in an infectious animal room and autopsy room.

3) Leaving dissected, infected guinea pigs on the bench top through the lunch hour.

4) Disinfecting animal carcasses by boiling.

5) Cleaning a contaminated laboratory sewage holding tank without first decontaminating the tank.

6) "Killing" anthrax spores by boiling for 10 minutes.

7) Blowing unfiltered air from a variola virus laboratory toward an adjacent building where smallpox vaccine is produced.

8) Handling contaminated pipettes before they are autoclaved.

9) Failing to use needle-locking syringes when working with infectious cultures.

10) Failing to wrap a vial of lyophilized culture with disinfectant-soaked cotton before breaking.

11) Using coiled metal wires for transferring infectious liquids.

12) Handling potentially infectious blood specimens without gloves.

13) Not filtering the exhaust air from lyophilizing apparatus.

14) Shaking tubercle bacilli specimens without placing them in aerosol-tight containers.

15) Harvesting spinal cords from infected suckling mice by water pressure from a syringe.

16) Allowing children to come into the infectious disease laboratory.

17) Producing BCG vaccine in a building that also houses a laboratory handling virulent tubercle bacilli.

18) Reusing contaminated cardboard egg trays without sterilizing them.

To evaluate the procedures used in coping with less obvious types of hazards, a tabulation was made of the protective measures taken or the safety equipment used while carrying out eight common procedures. Table 52 lists the procedures observed and the percentage of instances in which the protective measures employed were judged inadequate. In most instances the inadequacy related to the possible aerosolization of infectious microorganisms rather than to contamination of surfaces.

Even though a procedure is likely to result in infectious aerosol, a satisfactory filter respirator will prevent inhalation of airborne organisms. But among 88 laboratories, 66 per cent used no respiratory protective devices. Thirty-two per cent used hospital-type gauze masks, which are known to offer limited protection, and only two per cent used an efficient respirator.

Twenty-four of the 102 laboratories had some method available for decontaminating entire rooms. In 11 instances formaldehyde solutions were sprayed or vaporized. Eight laboratories relied on portable ultraviolet fixtures for room decontamination, four used mists of ethylene glycol, and one used sprays of a detergent solution.

General cleanliness and orderliness of laboratory and animal rooms is one measure of the adequacy of the techniques and procedures. High standards of hygiene should be maintained in infectious disease areas, particularly in those in which diagnostic procedures are undertaken, to keep working areas reasonably free of dust and dirt. Failure to keep materials not in use stored properly, and failure to separate and label potentially contaminated wastes, are indications that the proper care also may not be taken when manipulating infectious cultures. The investigator's evaluation of housekeeping conditions in 102 laboratories suggested that poor housekeeping contributed to creating hazardous conditions in more than one-third of the laboratories. Housekeeping in the animal quarters was poorer than in laboratory rooms.

In recent years several authors have commented on the abuses by microbiologists in the wearing of knee-length white coats—the badge of honor of the scientist. For example, it has been pointed out that it is improper to wear the same coat in the infectious disease laboratory, the lunchroom, and the library. It has

TABLE 52. PROTECTIVE MEASURES TAKEN WHILE PERFORMING EIGHT COMMON PROCEDURES

Procedure	Ratio of Inadequate Protection to Total Observed	Per Cent Inadequate
Centrifuging	64/82	78
Lyophilizing	38/43	88
Grinding and blending	52/76	68
Injecting animals	57/76	75
Autopsying animals	60/77	80
Aerating cultures	52/57	91
Inoculating and harvesting eggs	39/51	76
Routine diluting and plating	47/75	63

been suggested that the microbiologist fails to use his uniform according to the standards that he preaches to surgeons.[1] Among the male employees of the laboratories surveyed, 90 per cent wore white coats over their street clothes when handling infectious microorganisms. Frequently, white coats were not removed when the scientist left the laboratory to eat lunch or to work in a clean office. In ten per cent of the laboratories there was at least one area where a complete change of clothes was required for entrance. Female technicians in a number of laboratories wore white uniforms to work. Shoes were changed more frequently than clothing in the infectious laboratories.

D. SUMMARY

This chapter characterizes the microbiological laboratory accident problem in terms of accidents and infections, the environment in which they occur, and the laboratory techniques and procedures used.

A general conclusion drawn from the data is that control or elimination of accidental laboratory injuries, and in particular of infectious diseases, is a problem of significant concern in laboratory institutions. The problem is not confined to one or several institutions where high-hazard work is in progress, but appears to be ubiquitous wherever disease organisms are used. Moreover, students are presented with microbiological hazards to such a degree that educational institutions also should be concerned.

In a number of reported instances large segments of a laboratory population have become accidentally infected. However, normally, accidental infection rates vary from less than one to four or five per million man-hours worked. Infection rates

[1]Editorial: "Laboratory Infections," Lancet, 2, (1956) pp. 880-881.

vary more with time than lost-time injury rates, which appear to be around four injuries per million man-hours. A reasonable estimate of a combined mechanical, chemical, and infectious rate for laboratories is 6.25 per million man-hours. Usually one-half or more of the rate will be due to accidental infections.

When accident severity is measured by the death rate, the severity of laboratory infections in most instances is higher than is typical for motor vehicle accidents. The estimated combined case fatality rate for laboratory infections is 4.0 per million man-hours worked.

Non-lost-time accidents in laboratories occur at an estimated frequency of 109 per million man-hours worked.

Most of the persons in laboratories who become infected are those who directly handle infectious materials. Laboratory technicians are the largest exposed group and sustain the largest number of accidents and infections.

The body parts involved in lost-time laboratory accidents distribute themselves atypically because of chest involvement due to respiratory infections. With non-lost-time accidents, the upper extremities are more frequently involved than other body parts.

The average age of accident-involved persons may be expected to be about the same as that of the exposed population. However, the younger age groups are usually involved in more than their share of non-lost-time accidents and infections. No difference in accident involvement related to the sex of the persons can be detected.

Although seasons of the year or days of the week appear not to have an important or consistent influence on accident occurrence, at Fort Detrick accidents occur more frequently in the mornings than in the afternoons.

Diseases caused by bacteria are more frequent in the laboratory than those caused by viruses, rickettsiae, and fungi combined. However, virus infections will probably increase in relative frequency as the science of virology expands. In the recent past, the most frequently occurring bacterial diseases have been tuberculosis, brucellosis, typhoid fever, tularemia, dysentery, and anthrax. Viral and rickettsial diseases of most importance are Q fever, hepatitis, equine encephalomyelitis virus disease, psittacosis, and Rocky Mountain spotted fever. The fungal diseases of greatest significance are coccidioidomycosis and histoplasmosis.

When the risk of infectious laboratory work at educational institutions is compared with that at private laboratories and government or state non-educational institutions, it is found that, in relation to the number of people at risk, educational institutions are not as well off as private laboratories. However, when judged according to function, research activities are more hazardous than routine laboratory work or teaching.

A significant proportion of accidental laboratory infections may remain undetected unless a serological screening program or equivalent is carried out to detect nonclinical cases.

A consideration of the environment in relation to accidents and infections in more than a hundred laboratory institutions reveals a wide-spread laxity in utilizing design criteria and equipment that have been developed to improve safety by the engineering approach. Infectious facilities in educational institutions are in the greatest need of more and better equipment and facilities for improving laboratory safety.

Many reasons may be advanced for the deficiencies, but the cost of construction is most conspicuous. There is no evidence that the amount of space available in most laboratories is limited enough to create hazards. In spite of the introduction of tissue culture techniques, animal use in laboratories tends to increase, but without an equivalent increase in safe facilities for experimental animals. On the basis of circumstantial evidence it appears that the environments in many infectious disease laboratories are not providing a positive deterrent to accidents and infections in the man-environment-agent triad.

Some laboratory procedures with infectious materials are inherently hazardous and are easily recognized as such. Research with other laboratory procedures shows that infectious hazards not easily recognized or detected may be typical of most of them. Contamination of the environment with small quantities of airborne infectious microorganisms is probably the most prevalent type of infection-producing hazard. Observations made during a survey of infectious disease laboratories reveal a substantial lack of attention to commonly recognized factors contributing to accidents and infections, as well as a lack of attention to those that are more difficult to recognize.

V. LABORATORY ACCIDENT CAUSAL FACTORS--ACCIDENT CLASSES, TYPES, AND AGENCIES

In the previous chapter, following the epidemiological approach to accident cause determination, the investigator evaluated a number of factors that are helpful in characterizing the nature of laboratory accidents: factors that can be considered in cause determination and that provide the basis for formulating specific hypotheses regarding cause.

This and subsequent chapters are a progressively detailed treatment of causally related data. They follow the accident cause data classification system established by the American Standards Association, suitably modified and expanded to allow convenient categorization of data relative to laboratory infections and to the subproblems outlined in Section I. In them, data collected from Fort Detrick and several other research institutes and from the literature are used where applicable. Greater attention is ordinarily given to the data collected at Fort Detrick. The Fort Detrick data relate to the four-year period 1959 through 1962 because these data were available to the investigator in complete detail and were transformed to keysort cards for convenience and accuracy of analysis. Data from NIH and CDC relate to the periods 1954 through 1956 and 1959 through 1962 respectively. Where indicated, other time intervals are analyzed either to provide more significant frequencies for consideration or to illustrate trends.

Type classification of accidents is a part of the usual analysis for causal factors; its use allows relatively large amounts of accident information to be assembled in orderly and systematic form. Some information about individual accidents is lost during classification, but this loss is offset by the increased reliability resulting from the use of larger samples for analysis.

Many category sets for typing accidents can be devised, some more useful than others in elucidating causal factors. For example, classification according to the extent of injury or accident outcome may provide only limited information on cause, although useful in pointing to high risk areas. Classification according to manner of contact or exposure, or by task being performed, adds some insights to possible causal factors. Some of the possible ways in which accidents can be typed, such as by occupation, sex, age, time, part of the body involved, and outcome were considered in Section IV because they were also useful in characterizing the laboratory accident problem.

Classifications that are more directly related to causal factors or that provide a basis for testing hypotheses about causes are used in this and subsequent Sections. Classification of accidents in classes such as industrial, biological, or combined industrial and biological illustrates the relative role of causal factors typical of each class. This is important because, in other studies, causes have been found for only about 20 per cent of the laboratory infections.

Accident classification according to the type of injury can provide useful causal information. However, in such category sets, provision must be made for the inclusion of laboratory infections. The obvious disadvantage of this classification is that "no-injury" accidents or "near-misses" are not ordinarily provided for. Typing of accidents according to the task or operation being performed at the time of the accident provides useful information, particularly when data on specific subtasks or procedures are available for more detailed study. With laboratory infections the disadvantage is that, since accidents are usually not detected, the exact time of the infecting incident is difficult to determine. However, it is usually possible at least to specify the mode of infection, e.g., inhalation, aspiration, etc. Also, consideration can be given to the specific disease microorganisms involved and to problems related to the use of animals in the microbiological laboratory.

Double criteria classifications, or contingency table comparisons, also are useful in identifying causal factors. Such comparisons, for example, allow observations to be made about laboratory tasks in relation to predominant modes of infection or to major types of injuries.

The most widely used classification for accident types places accidents in categories according to the manner of contact of the injured person with an object or substance, or the movement or exposure of an individual that resulted in his injury. This classification was used with the laboratory accidents, except that provision was made to include noninjurious events and that additional categories were established for contacts or exposures typical of the microbiological laboratory.

In Section IV some information on the relative frequency of lost-time accidents in laboratory institutions was summarized. The present discussion also deals with this relationship, but in relation to time intervals in which the most complete data were available. The ratios shown below provide a basis for subsequent hypotheses. The required assumptions are that the causes of lost-time and non-lost-time accidents are essentially the same and that, for a particular institution, ratios of lost-time vs. total accidents provide a basis for detecting circumstances, events, techniques, or equipment that present risks that are greater or less than average. For the institutions studied, the over-all accident ratios were:

Institution, Dates	Ratio, Lost-Time to Total Accidents
NIH, 1954-1956	1:19
CDC, 1959-1962	1:10
Fort Detrick, 1959-1962	1:26

The possible usefulness of these ratios can be illustrated as follows: Lost-time accidents at Fort Detrick occur at an average frequency of one for each 26 total accidents. In partitioning accident types, if it is found that a specific subtype of accident results in one lost-time incident for each 10 accidents, a basis is provided for suspecting that subtype to be greater than average in risk level.

A. ACCIDENTS CLASSIFIED ACCORDING TO CLASS

Although the NIH safety records examined by the investigator were not sufficiently detailed to allow classification of all accidents as industrial, biological, or combined, the lost-time accidents could be so classified. As in other analyses in this report, all occupational diseases were classified as lost-time. Two types of occupational diseases were classified: (i) occupational disease—a service-connected disease due to a pathogenic agent, and (ii) suspected occupational disease—determination in doubt concerning service connection. Cases in these two categories in which it was most probable that an occupational infection had occurred are included below. Typical examples of "suspected occupational disease" that were judged to qualify as an occupational disease are:

Febrile illness following a monkey bite

Diarrhea after working with sick monkeys

Choriomeningitis after working with the causative agent

Conjunctivitis after working with cats with infected eyes

Coxackie virus disease after working with the virus

The 178 lost-time accidents occurring at NIH between 1954 and 1956 are classified as follows:

Industrial	110 or 61.8%
Biological	55 or 30.9%
Combined, industrial and biological	13 or 7.3%

Thus, infectious microbial agents were involved in 38 per cent of the lost-time accidents; 31 per cent were due to infections without concurrent physical injury. When all reported accidents at NIH from 1954 to 1956 were considered, it was found that no more than 7 per cent of 3729 accidents involved disease-producing agents. But, as shown above, these resulted in about 31 per cent of the lost-time accidents.

Two other classifications of accident types at NIH are of interest. These are non-lost-time accidents that were classified as potentially disabling injuries and those classified as potentially resulting in occupational disease. Of 843 accidents 19 per cent, or 157, were judged to have the potential of producing disabling injuries. Together, these data provide a basis for evaluating the seriousness of industrial vs. biological accidents:

Potentially Serious Accidents	Lost-Time	Total	Ratio
Industrial	110	686	1:6
Biological	55	157	1:3

Thus, for accidents classified as potentially serious, a greater proportion of those involving infectious agents resulted in infection than did the industrial accidents result in disabling injury.

About 40 per cent of 489 accidents at CDC between 1959 and 1962 involved infectious materials. The accidents are classified as follows:

Industrial	290 or 59.3%
Biological	77 or 15.7%
Combined, industrial and biological	122 or 25.0%

The proportion of each group that resulted in loss of time is shown below:

	Lost-Time	Total	Ratio
Industrial	38	290	1:8
Biological	8	77	1:10
Combined, industrial and biological	2	122	1:61

About the same proportion of industrial and biological accidents resulted in lost time. (1:8 vs. 1:10) The "combined" accidents were mostly bites and scratches from infected animals.

Analysis of laboratory accidents at Fort Detrick for the years 1959 through 1962 showed the distribution of accidents to be:

Industrial	561 or 46.1%
Biological	450 or 36.9%
Combined, industrial and biological	207 or 17.0%

As compared with NIH and CDC, a smaller proportion of the accidents were of the industrial class. The data below show the relative proportions of Fort Detrick lost-time to total accidents in each group:

	Lost-Time	Total	Ratio
Industrial	9	561	1:62
Biological	37	450	1:12
Combined, industrial and biological	1	207	1:207

These data suggest the greater seriousness of biological accidents as compared with the other two classes.

The tabulations on classes of accidents occurring at NIH, CDC, and Fort Detrick provided a basis for testing the hypothesis that biological accidents are no more serious as a cause of lost time than are accidents not involving infectious materials. In other words, the hypothesis was that for an equal number of industrial and biological accidents, the number of biological lost-time accidents would be no greater than the number of industrial lost-time accidents. To test this hypothesis the relative frequency of non-lost-time accidents in each category was used to establish the number of expected lost-time accidents.

Table 53 shows the results of the chi square analyses. At all three institutions the distribution of types of lost-time accidents was significantly different from that predicted by the numbers of non-lost-time accidents. However, with the CDC data the biological lost-time accidents were closely predicted from the relative frequency of biological non-lost-time accidents, but industrial accidents appeared higher than average in risk of lost time. With the NIH and Fort Detrick data, the hypothesis was rejected because the number of biological lost-time accidents was more than twice that expected. Thus at two institutions the seriousness of biological accidents in relation to their frequency was greater than the seriousness of industrial accidents. At a third institution the seriousness was at least equal to that expected.

From the above data a general estimate was made of major types of accidents to be expected in infectious disease laboratories. As many as 50 to 60 per cent may be expected not to involve exposure to infectious materials; the remaining accidents will be mostly those involving only infectious materials without mechanical injury. Less than 15 per cent would be expected to be combined industrial and biological accidents. The combined accidents do not tend to be as serious (in loss of time) as the others. Biological accidents are usually more serious than industrial accidents.

TABLE 53. CLASSES OF ACCIDENTS AT THREE INSTITUTIONS

Accident Class	Number of Lost-Time Accidents		
	Observed	Expected	Chi Square
	NIH		
Industrial	110	140	
Biological	55	25	41.014[a]
	CDC		
Industrial	38	28	
Biological	8	7	
Combined	2	13	13.022[b]
	Fort Detrick		
Industrial	9	22	
Biological	35	17	
Combined	3	8	29.866[b]

a. At df = 1 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.
b. At df = 2 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

From the data collected, it appears that about one in ten laboratory accidents results in loss of time.

These estimates are shown below:

Accident Type	Estimated Per Cent of Total Accidents	Estimated Ratio of Lost-Time to Total Accidents
Industrial	60.0	1:10
Biological	26.7	1:7
Combined	13.3	1:114

Table 54 shows a classification of the accidents at three institutions according to the occupation of the involved persons. It is clear that the bulk of the accidents occurred to technicians, animal caretakers, and trained scientists.

TABLE 54. CLASSIFICATION OF ACCIDENTS ACCORDING TO THE OCCUPATION OF INVOLVED PERSONS

Occupation	Per Cent of Accident-Involved Persons in Indicated Accident Class		
	Industrial	Biological	Combined
	NIH		
Technicians and animal caretakers	37.0	47.1	
Trained scientific personnel	17.2	33.0	
Laborers	8.3	4.0	
Maintenance personnel	16.5	5.1	
Others	21.0	10.8	
	CDC		
Technicians	34.4	46.1	61.1
Trained scientific personnel	4.6	38.4	22.1
Animal caretakers	9.8	10.3	13.7
Laborers	8.4	2.6	0.8
Maintenance personnel	20.4	1.3	0.0
Others	22.4	1.3	2.3
	Fort Detrick		
Technicians	40.0	71.0	52.6
Trained scientific personnel	21.2	17.7	25.6
Animal caretakers	16.1	3.7	19.9
Maintenance personnel	15.1	6.9	0
Others	7.6	0.7	1.9

The Fort Detrick records revealed the distribution of the total number of laboratory-assigned personnel to be as follows:

Laboratory technical assistants	44.2%
Trained scientific personnel	37.6%
Animal caretakers	17.0%
Laboratory workers	1.2%

These percentages were used to obtain predicted numbers of accident-involved people in the three accident classes. Biological accidents showed greater deviations between the observed and expected frequencies than the other two accident classes. Laboratory technical assistants and animal caretakers had approximately twice the expected number of biological accidents; trained scientists and laboratory workers had only about half the number expected. These trends were generally true with industrial and combined accidents, but not to the same degree. One notable exception was that laboratory workers sustained far more industrial accidents than was expected. The expected and observed accident frequencies are shown in Table 55.

TABLE 55. EXPECTED AND OBSERVED ACCIDENTS ACCORDING TO OCCUPATION

Occupation	Number of Accident-Involved People by Class					
	Industrial		Biological		Combined	
	Observed	Expected	Observed	Expected	Observed	Expected
Laboratory technical assistants	219	198	909	524	109	90
Trained scientific personnel	102	168	221	446	48	77
Animal caretakers	88	76	47	20	40	35
Laboratory workers	39	6	8	14	7	2

Section IV showed that the age distribution of persons involved in non-lost-time Fort Detrick accidents was significantly different from the age distribution of the total employed laboratory population. Examination of age-group data, divided according to accident class (Table 56) provides additional information.

The frequency of industrial accidents was distributed by age in a manner not significantly different from that of the exposed population. However, for biological and combined accidents, the younger, 20- to 29-year groups (possibly those with less technical training) had more than their expected share of accidents. The 40- to 49-year-old group also had more biological accidents than expected; the other groups had fewer biological and combined accidents than expected.

Section IV also presented evidence that females had fewer than their share of accidents. Partitioning of the accident-involved people,* as shown in Table 57, revealed that this difference was due to female involvement in a significantly fewer number of biological accidents; with industrial and combined accidents there was no

*Attention is called to the fact that the number of Fort Detrick accidents recorded was less than the number of accident-involved people, because some biological accidents involved two or more people. According to the hypothesis being tested, the number of accidents or the number of accident-involved people will be tabulated.

TABLE 56. ACCIDENTS ACCORDING TO AGE GROUP AND ACCIDENT CLASS

Age Group	Industrial		Biological		Combined	
	Observed	Expected	Observed	Expected	Observed	Expected
20-29	117	106	193	172	103	41
30-39	225	225	352	368	57	87
40-49	122	125	223	204	26	48
50-59	18	30	40	49	6	11
60	19	15	9	24	1	6
Chi squares	7.081[a]		16.058[b]		120.624[b]	

a. At df = 4 and at the 0.05 level of significance, the hypothesis of equal frequencies is accepted.
b. At df = 4 and at the 0.05 level of significance, the hypothesis of equal frequencies is rejected.

TABLE 57. DISTRIBUTION OF ACCIDENT-INVOLVED PEOPLE BY ACCIDENT CLASS AND SEX

Sex	Industrial		Biological		Combined	
	Observed	Expected	Observed	Expected	Observed	Expected
Male	540	534	1347	1315	204	200
Female	28	34	52	84	9	13
Chi squares	1.126[a]		12.969[b]		1.311[a]	

a. At df = 1, hypothesis of equal frequencies accepted at the 0.05 level of significance.
b. At df = 1, hypothesis of equal frequencies rejected at the 0.05 level of significance.

statistical evidence to refute the hypothesis of equal accident involvement due to sex.

It is possible that females tend to be safer workers than males, particularly in view of other evidence that shows that routine microbiological manipulations, those that females most often would be doing, are among the most frequent tasks leading to biological accidents.

Seven categories of laboratory work, designated as tasks, were associated with approximately 80 per cent of the Fort Detrick accidents. In decreasing order of frequency these were:

1)	Washing, cleaning, or sterilizing laboratory equipment and glassware	15.3%
2)	Repairing or decontaminating laboratory rooms or buildings	13.6%
3)	Doing routine microbiological laboratory procedures	12.4%
4)	Performing aerobiological experiments	10.8%
5)	Exposing, injecting, or autopsying animals	9.9%
6)	Feeding, transferring animals, and cleaning cages	9.0%
7)	Handling bulk quantities of infectious material	8.6%

When the accidents were partitioned according to the presence or absence of infectious materials, the predominant tasks for each group were not the same. For accidents in which infectious organisms were present (biological accidents), the major tasks being performed were:

1)	Doing routine microbiological laboratory procedures	16.4%
2)	Handling bulk quantities of infectious material	14.8%
3)	Performing aerobiological experiments	14.7%
4)	Exposing, injecting, or autopsying animals	13.9%
5)	Washing, cleaning, or sterilizing laboratory equipment and glassware	11.6%
6)	Packaging or transporting infectious cultures	8.0%

For those accidents not involving infectious cultures (industrial accidents) the most common tasks were:

1)	Repairing or decontaminating laboratory rooms or buildings	24.1%
2)	Washing, cleaning, or sterilizing laboratory equipment and glassware	20.3%
3)	Feeding, transferring animals, and cleaning cages	14.0%
4)	Setting up small laboratory equipment and apparatus	10.6%
5)	Moving or handling heavy laboratory equipment	7.5%
6)	Doing routine microbiological laboratory procedures	6.8%
7)	Performing aerobiological experiments	5.5%

Each of the above three lists of tasks constituted approximately 80 per cent of the accidents in the specified category. Fifty-four per cent of the 1218 accidents were ones in which infectious cultures were present. Therefore, it may be concluded that the laboratory accidents were about equally divided insofar as the presence or absence of infectious cultures is concerned, but that there was a substantial difference in the type of laboratory work being done when the two classes of accidents occurred.

Although the frequencies for the biological and industrial laboratory accidents were approximately the same, biological accidents were the group having the greatest proportion of the lost-time occurrences (81 per cent). The ratios of lost-time to total accidents for the two groups were:

Biological accidents	1:17
Industrial accidents	1:62
All accidents	1:26

Thus, for the frequency of lost time, accidents involving infectious cultures were of higher risk than those not involving pathogens. This observation was confirmed by a chi square analysis wherein the expected lost-time accidents were obtained from the relative frequency of non-lost-time accidents (Table 58).

TABLE 58. OBSERVED AND EXPECTED FREQUENCIES OF BIOLOGICAL AND INDUSTRIAL LOST-TIME ACCIDENTS

Accident Class	Lost-Time Accidents	
	Observed	Expected
Biological	38	25
Industrial	9	22
Chi square	13.352[a]	

a. At df = 1 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

It was next of interest to examine the ratios of lost-time and non-lost-time accidents in relation to the type of laboratory work being done. Of 13 categories of laboratory tasks only two, "setting up small laboratory apparatus" and "entering a laboratory area," were not associated with at least one lost-time accident. The relative hazards of the remaining tasks, expressed as the ratios of lost-time to total accidents, are shown in Table 59.

As a rough measure, those accidents associated with tasks whose ratios are higher than 1:26 are probably more than average in risk of lost time. It is to be

TABLE 59. RELATIVE HAZARDS OF LABORATORY TASKS

Tasks	Ratio, Lost-Time to Total Accidents		
	Biological	Industrial	Combined
Inoculating, harvesting eggs	1:4		1:4
Doing routine laboratory procedures	1:6	1:31	1:8
Handling bulk infectious cultures	1:16		1:16
Packaging, transporting infectious cultures	1:17		1:17
Moving, handling heavy laboratory equipment		1:17	1:19
Chemical titrations and tests		1:20	1:27
Repairing or decontaminating laboratory rooms or buildings	1:19	1:36	1:29
Feeding, transporting animals, cleaning cages	1:34	1:63	1:49
Exposing, injecting, autopsying animals	1:87		1:107
Performing aerobiological experiments	1:92		1:117
Washing, cleaning, sterilizing laboratory equipment and glassware	1:73		1:165

noted again that most of the accidents that have ratios suggesting higher than average hazard of lost time are those that involve use of infectious agents.

Consideration was given to the body parts involved in the three classes of accidents because of the causal factors that can be so derived and the possible demonstration of how personnel protective equipment could have prevented some injuries. For example, although it is obvious that protective clothing does not prevent injuries to the back, protective equipment such as safety glasses and protective gloves will prevent injuries to the eyes and hands.

Table 60 shows the relative involvement of body parts in the three classes of laboratory accidents. The body-part category "systemic" was established to provide for respiratory exposures to infectious materials in biological accidents and for exposures to chemical fumes and vapors in industrial accidents. For the biological accidents, systemic exposure accounted for 98 per cent of the accidents. The remaining biological accidents involved spilling or spraying infectious material onto the face, chest, arms, etc. From these data the importance of procedures or acts that produce aerosol contamination of the environment becomes immediately apparent. Moreover, the possible use of respiratory protective devices as a means of avoiding laboratory infections is suggested.

With industrial accidents, fingers and thumbs were the single most frequently injured part of the body, followed by hands, eyes, and arms. Again, it becomes

TABLE 60. BODY PARTS INVOLVED ACCORDING TO PER CENT OF ACCIDENT CLASS

Body Part Involved	Per Cent of Accident-Involved People		
	Industrial	Biological	Combined
Head and face	7.0	0.2	2.3
Eyes	10.6	0.3	7.3
Back	6.0	0	0.9
Abdomen and chest	3.9	0.8	0
Arms	9.7	0.2	6.8
Hands	10.9	0.3	10.5
Fingers and thumbs	34.4	0	69.0
Legs	6.3	0.2	2.7
Feet and toes	4.7	0.1	0.5
Systemic	6.5	97.9	0

obvious that a portion of these accidents might have been prevented by proper protective devices. Moreover, for laboratory work, the top areas of the body, those extending above the laboratory-bench height, are in greatest danger of injury because these parts are used to perform most laboratory manipulations.

With combined industrial-biological accidents, almost 70 per cent involved the fingers and thumbs and 11 per cent involved the hands. These were primarily bites and scratches inflicted by experimental animals. Failure to use protective gloves is suspected of being a predominant cause for these accidents.

Table 61 classifies accident-involved people according to affected body part and class of accident.

The numbers within parentheses represent lost-time accidents. Not only does this comparison demonstrate the importance of biological inhalation accidents (systemic), as they apply to both the total and lost-time accidents, but, based on the ratios of lost-time to total accidents, estimates can be made of the relative risk level of accidents with regard to causing loss of work time.

With industrial accidents, it is observed, for example, that although injury to fingers and thumbs was the most frequent, the risk of lost of work time for these accidents was low. In order of decreasing risk of lost time, the body parts rate as follows:

Industrial	Biological	Combined
Feet and toes	Systemic	Arms
Back	Abdomen and chest	Fingers and thumbs
Legs	Eyes	Hands
Abdomen and chest	Hands	Eyes
Head and face	Arms	Legs
Fingers and thumbs	Legs	Head and face
Hands	Head and face	Back
Eyes	Feet and toes	Feet and toes
Arms		
Systemic		

TABLE 61. BODY PARTS INVOLVED IN INDUSTRIAL, BIOLOGICAL, AND COMBINED ACCIDENTS

Body Part Involved	Number of Accident-Involved People			
	Industrial	Biological	Combined	Totals
Head and face	41(1)[a]	2	5	48(1)
Eyes	62	4	16	82
Back	35(2)	0	2	37(2)
Abdomen and chest	23(1)	10	0	33(1)
Arms	57	3	15(1)	[illegible]5(1)
Hands	64	4	2[illegible]	91
Fingers and thumbs	203	0	152(2)	3[illegible](2)
Legs	3[illegible](2)	2	6	45(2)
Feet and toes	28(3)	1	1	[illegible]
Systemic	38	129[illegible]([illegible])	0	1[illegible]
Totals	588(9)	1324(35)	220(3)	21[illegible]

a. Parentheses designate accidents resulting in lost time.

Thus it is apparent that, according to the class of accident and the involved body part, one may expect a wide variation in the risk of loss of time. It follows, also, that different types of protective equipment would be required to protect against the most severe injuries in each category and that causal factors may likewise vary considerably.

B. ACCIDENTS CLASSIFIED ACCORDING TO NATURE OF INJURY

Consideration of the nature of accident-caused injuries is of value in safety studies. Not only does such a classification prescribe the type of medical care that should be provided for persons injured on the job, but much causally related and preventive information results. For example, a high frequency of hernias among a work population immediately suggests that employees are required to lift loads that are too heavy, or have not been properly instructed, or both.

Information relating to the nature of accidental injuries from a variety of sources is summarized below. In order to provide an acceptable classification for the data, the category set used included chemical and biological exposures.

Tables 62 and 63 show data on lost-time injuries among hospital clinical laboratory employees during 1953.[1] Occupational diseases, including infectious diseases, were the second most frequent type of injury among all the employees, but the most frequent type occurring to technicians. Lacerations, occupational diseases, burns, and strains and sprains were the most important types of injuries, accounting for almost three-quarters of the total.

TABLE 62. NUMBER AND NATURE OF LOST-TIME ACCIDENTS OCCURRING TO 22,549 CLINICAL LABORATORY EMPLOYEES, 1953

Nature of Injury	Technicians	Helpers	Others	Per Cent of Total Accidents
Lacerations	31	11	6	24.9
Occupational diseases	36	6	1	22.3
Burns	14	7	3	12.4
Strains and sprains	22	4	0	13.5
Contusions	9	4	1	7.3
Fractures	10	0	1	5.7
Hernias	4	2	0	3.1
Eye irritations	2	0	0	1.0
Other or unclassified	12	7	0	9.8
Totals	140	41	12	100.0
Per cent of total	72.6	21.2	6.2	

[1]"Work Injuries and Work-Injury Rates in Hospitals," Bulletin No. 1219, Bureau of Labor Statistics, Feb. 1958, pp. 50-53.

In Table 63, types of lost-time accidents occurring to hospital laboratory technicians and laboratory helpers are classified, together with the number expected based on the relative frequency with which accidents of each type occurred to all hospital employees during 1953. It is clear that occupational diseases, lacerations, and burns occurred to the laboratory employees more frequently than to other employees, and that the frequency of strains and sprains, contusions, and fractures was less than expected. Thus the nature of the injuries observed among laboratory employees reflects the nature of the hazards of laboratory work and may be considerably different from that for non-laboratory biomedical workers.

TABLE 63. OBSERVED AND EXPECTED LOST-TIME INJURIES SUSTAINED BY HOSPITAL LABORATORY WORKERS, 1953

Nature of Injury	Number of Injuries	
	Observed	Expected[a]
Occupational diseases	42	13.8
Lacerations	42	20.8
Strains and sprains	26	58.2
Burns	21	11.2
Contusions	13	44.0
Fractures	10	18.5
Hernias	6	4.5
Eye irritations	2	1.5
Other and unclassified	19	7.4

a. Based on the nature of 14,593 lost-time injuries occurring to all hospital personnel.

Table 64 shows the frequency of the various types of injuries at three institutions. There was good agreement with regard to the relative frequency of the injury types at the three institutions, as shown by rank order correlation coefficients (Table 64).

It is not to be expected, of course, that the potential seriousness or severity of each type of accident would be the same. In fact, by their very nature some injuries rarely incapacitate but others, such as fractures, usually do. Estimates of relative risks were obtained by comparing ratios of total to lost-time accidents classified according to the nature of the injury. Although the predictive value of these estimates may be limited because of the marked influence one lost-time accident can have, in a general manner they are helpful in pointing to the classes of

TABLE 64. LABORATORY ACCIDENTS CLASSIFIED ACCORDING TO THE NATURE OF THE INJURIES

Nature of Injury	Fort Detrick (A)		CDC (B)		NIH (C)	
	Number	Per Cent	Number	Per Cent	Number	Per Cent
Lacerations	467(3)[a]	38.5	155(5)	48.7	206(25)	22.1
Biological exposures	405(35)	33.3	77(11)	24.3	90(18)	9.6
Contusions	95(1)	7.8	20(2)	6.3	170(35)	18.2
Eye injuries	82	6.7	25(3)	7.9	107(7)	11.5
Burns	56(4)	4.6	13	4.1	65(6)	6.9
Strains and sprains	52(3)	4.3	22(8)	6.9	161(47)	17.2
Chemical exposures	52	4.3	4	1.2	49	5.3
Dermatitis	8	0.6	0	0	57	6.1
Fractures	1(1)	0.1	2(2)	0.6	28(8)	3.1
Totals	1218(47)	100.0	318(31)	100.0	933(146)	100.0

a. Parentheses denote number of lost-time accidents.

Rank order correlation coefficients

r (AB) = 0.89, "t" = 5.221*
r (AC) = 0.82, "t" = 3.747*
r (BC) = 0.70, "t" = 2.606*

*At df = 7 and at the 0.05 level of significance, the hypothesis that the population coefficient is zero is rejected.

accidents that should receive emphasis. Table 65 shows some estimates of risk based on the data of Table 64.

At Fort Detrick, except for fractures, the greatest risks of lost time were biological exposures, burns, and strains and sprains. At CDC, except for fractures, the most important categories were strains and sprains, biological exposures, and eye injuries. The NIH data identify the importance of strains and sprains, biological exposures, and contusions.

For each injury type, the accident data usually contained sufficient information to allow subclassification based on what act, equipment, etc., caused the injury. The accidents at Fort Detrick and CDC were analyzed according to appropriate subcategories. Such tabulations are somewhat long and involved, but they provide a means of locating the most frequently occurring causes associated with each

TABLE 65. ESTIMATION OF RISK OF LOSS TIME ACCORDING TO THE NATURE OF THE INJURY

Nature of Injury	Ratio of Lost-Time to Total Accidents		
	Fort Detrick	CDC	NIH
Lacerations	1:156	1:31	1:8
Biological exposures (internal)	1:12[a]	1:7[a]	1:5[a]
Eye injuries		1:8[a]	1:15
Contusions	1:95	1:10	1:5[a]
Burns	1:14[a]		1:11
Strains and sprains	1:17[a]	1:3[a]	1:3[a]
Fractures	1:1[a]	1:1[a]	1:4[a]
Over-all ratios	1:22	1:10	1:6

a. Risk of loss of work time probably greater than average for that institution.

injury type. The detailed breakdown for the Fort Detrick and CDC injury types is shown in Table 66. The degree of agreement of subtypes is obvious.

Laceration-type injuries at the two institutions were due primarily to:

Animal bites and scratches

Cuts from clean glassware

Syringe self-inoculations with infectious materials

Cuts from contaminated glassware

Cuts from laboratory apparatus and equipment.

Many biological exposures resulted from spilling infectious materials in a manner possibly resulting in aerosol formation, but most infections were not associated with known instances of microorganism escape. Among the other recorded types of internal biological exposures, both oral aspiration of infectious materials and microorganism escape following the failure of ventilation systems resulted in laboratory infections.

Most contusions were caused by bumping or falling against laboratory equipment, being hit by moving objects, falling at the same level, or being caught in or between objects.

TABLE 66. CLASSIFICATION OF ACCIDENTS ACCORDING TO TYPE AND SUBTYPE OF THE NATURE OF THE INJURIES

Injury	Per Cent of Accidents	
	Fort Detrick	CDC
Lacerations		
Animal bites and scratches	20.3	21.[illegible][a]
Cuts from apparatus and equipment	18.6	5.8
Cuts from clean glassware	16.7	25.2[a]
Syringe self-inoculation with infectious materials	14.6[a]	12.9[a]
Cuts from contaminated glassware	8.6	18.7
Cuts from building structures	5.4	1.3
Cuts from tools	5.1	0.6
Cuts from cage and cage racks	4.3	8.4
Syringe self-inoculation with noninfectious materials	3.6	-
Cuts from autopsy instruments	1.5	5.2
Miscellaneous	1.3	-
Biological Exposures (Internal)		
Suspected miscellaneous exposures or infections due to unknown source	52.9[a]	14.3[a]
Spill of agent, possibly resulting in aerosol	33.8	16.9
Aerosol release due to glove break or ventilation failure	6.4[a]	16.9
Splash of infectious material on body	3.7	15.6
Possible exposure during animal autopsy or injection	2.2	14.3
Oral aspiration of infectious material	0.5[a]	13.0
Splash of infectious material directly into face	0.5	9.0
Contusions		
Bumped against laboratory equipment	40.0[a]	15.0
Hit by moving objects	22.1	35.0[a]
Caught in or between objects	26.3	-
Falls, same level	4.2	20.0[a]
Falls, different level	2.1	-
Falls against animal equipment	1.1	25.0
Miscellaneous	4.2	5.0
Eye Injuries		
Chemicals or chemical fumes in eye	36.6	32.0[a]
Inert objects in eye	25.6	32.0[a]
Ultraviolet conjunctivitis	24.4	24.0[a]
Splash of infectious material in eye	13.4	12.0

TABLE 66. CLASSIFICATION OF ACCIDENTS ACCORDING TO TYPE AND SUBTYPE OF THE NATURE OF THE INJURIES (Continued)

Injury	Per Cent of Accidents	
	Fort Detrick	CDC
Burns		
From autoclaves, sterilizers, and steam lines	39.3	53.8
From hot solutions	21.4[a]	-
From chemical vapors or solutions	12.5[a]	15.4
During maintenance and repair (hot lead, etc.)	8.9	-
From open gas flames	7.1	30.8
From welding operations	5.4	-
From electrical shock	3.6	-
Ultraviolet skin burn	1.8	-
Strains and Sprains		
Lifting or pulling equipment	63.5[a]	68.2[a]
Slipped without falling	9.6	4.6
Working in cramped or awkward position	7.7	-
Climbing on equipment	7.7	-
Fall, same level	-	13.6[a]
Fall, different level	-	13.6[a]
Miscellaneous	11.5	-
Chemical Exposures (Internal)		
Inhalation of toxic chemical fumes	50.0	50.0
Oral aspiration of chemical	7.7	25.0
Inhalation of solvent fumes	21.2	25.0
Splash of toxic chemical into mouth	1.9	-
Miscellaneous	19.2	-
Dermatitis		
From chemical fumes and solutions	25.0	-
From miscellaneous or unknown causes	75.0	-
Fractures		
Hit by moving object	100.0[a]	-
Lifting, pushing, and pulling	-	50.0
Fall, same level	-	50.0

a. One or more lost-time accidents included.

Injuries to the eyes were due primarily to:

Chemical substances in the eyes

Inert objects in the eyes

Exposure to germicidal ultraviolet radiation

Burns resulted mostly from steam apparatus and sterilizing equipment, from open gas flames, from heated solutions, or from caustic chemicals.

The most important types of strains and sprains were those from lifting or pulling equipment, slipping, and falling from the same or different level.

Chemical exposures were due primarily to the inhalation of toxic chemicals or solvent fumes and oral aspiration of solutions.

In order to arrive at useful statements regarding the age, sex, and occupation of accident-involved people, the tasks they were performing at the time of their accidents, and the specific parts of the body injured in relation to the nature of the injuries, it was necessary to deal with numbers of people rather than numbers of accidents. Data for these comparisons were available only for the Fort Detrick accidents.

The number of females vs. males who sustained injuries of various types was not substantially different from that expected from the proportion of females in the exposed population, except that no females had lost-time accidents. Six per cent of the exposed population were female and from two to six per cent of the accidents in each injury category occurred to females.

Ages were recorded for about 75 per cent of the Fort Detrick accident-involved people. Table 67 shows the nature of the injuries partitioned according to age groups.

Using these frequencies and predictions of the expected frequency of accidents for each injury group based on the age distribution of the total exposed population, chi square values were calculated to test the hypothesis that the observed accident distributions were not different from those expected, as shown in Table 68.

Only the age distribution for lacerations proved to be different from that expected. The 20- to 29-year group had more lacerations than expected; the 30- to 39- and 40- to 49-year groups had fewer than expected.

The occupations of persons involved in Fort Detrick laboratory accidents, classified according to the nature of the injuries, are shown in Table 69. Examination of this table shows it to be skewed in the direction of higher frequencies for laboratory technical assistants and trained scientific personnel who had biological exposures and lacerations.

A further analysis compared the frequency of accidents for each injury type, as it occurred to technicians, scientists, animal caretakers, and laboratory workers, with the frequencies expected from the proportion of these occupations in the laboratory work force. Technicians were found to have significantly greater frequencies of all types of injuries except contusions and strains and sprains, for which they had approximately the expected number of injuries. Trained scientific personnel had consistently lower accident frequencies than expected in all injury categories. Lacerations and eye injuries sustained by animal caretakers were about what would

TABLE 67. AGES OF FORT DETRICK ACCIDENT-INVOLVED PEOPLE ACCORDING TO THE NATURE OF THE INJURIES

Nature of Injury	Number of Accident-Involved People in Indicated Age Group				
	20-29	30-39	40-49	50-59	> 60
Biological exposures	181(11)[a]	405(15)	227(5)	37(4)	17
Lacerations	126	159	82	19	18
Contusions	14	37	23(1)	2	4
Eye injuries	17	26	20	0	0
Burns	14	23(3)	11(1)	4	2
Chemical exposures	7	28	11	2	0
Strains and sprains	10	21(1)	7(1)	4	2
Dermatitis	5	3	0	0	0
Fractures	0	0	1(1)	0	0

a. Parentheses denote number of lost-time accidents.

TABLE 68. ACCIDENT-INVOLVED PEOPLE IN RELATION TO AGE GROUP AND NATURE OF INJURY

Nature of Injury	Number of Accident-Involved People in Indicated Age Group								Chi Squares
	20-29		30-39		40-49		> 50		
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
Biological exposures	181	182	405	391	227	226	54	[illegible]	4.167
Lacerations	126	84	159	181	82	105	37	32	29.493[a]
Contusions	14	17	37	37	23	21	6	6	0.[illegible]20
Eye injuries	17	13	26	28	20	17	0	5	6.903
Burns	14	11	23	24	11	14	6	4	2.504
Chemical exposures	7	10	28	23	11	13	2	4	3.295

a. At df = 3 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

TABLE 69. LABORATORY ACCIDENTS CLASSIFIED ACCORDING TO NATURE OF INJURY AND OCCUPATION

Nature of Injury	Number of Accident-Involved People					
	Laboratory Technical Assistants	Trained Science Personnel	Animal Care-takers	Dishwashers and Janitors	Workmen and Others	Totals
Biological exposures	919(24)[a]	230(7)	40(1)	25(1)	105(2)	1319(35)
Lacerations	210	107(3)	86	30	34	467(3)
Eye injuries	46	12	10	1	13	82
Contusions	34	16	20	2	23	95(1)
Chemical exposures	29	12	4	3	4	52
Burns	32(2)	4	1	4	15(2)	56(4)
Sprains and strains	18(1)	8	14(2)	2	10	52(3)
Dermatitis	4	1	1	1	1	8
Fractures	0	0	0	0	1(1)	1(1)
Totals	1292(28)	390(10)	176(3)	68(1)	206(5)	2132(47)

a. Parentheses denote accidents resulting in lost time.

have been expected; biological and chemical exposures were less frequent than expected; contusions and strains and sprains occurred more frequently.

The task or job a person is doing at the time of an accident is not apparent from his occupation category. For example, it is not unusual for a technical assistant to be washing, cleaning, or sterilizing glassware or for a trained scientist to be examining animals or doing decontamination procedures. Therefore, an examination was made of the tasks being performed in relation to the nature of the injuries. These results (Table 70) show a concentration of biological exposures and lacerations occurring during the handling, transporting, or packaging of bulk infectious materials, during aerobiological experiments, during routine diluting and plating procedures, and during the washing, cleaning, or sterilizing of laboratory glassware; these accounted for more than 50 per cent of the accident-involved people. In regard to the risk of loss of work time, Table 70 shows that the greatest proportion of lost-time occurrences were a result of biological exposures associated with routine diluting and plating procedures. Biological exposures resulting from the handling, transporting, or packaging of bulk infectious materials were the second most important task-injury combination resulting in lost time. It is important also that lacerations, the second most frequent injury category, occurred at significant frequencies during most tasks but produced only three lost-time accidents during routine laboratory procedures.

TABLE 70. LABORATORY ACCIDENTS CLASSIFIED ACCORDING TO NATURE OF INJURY AND TASKS BEING PERFORMED

Nature of Injury	Routine Laboratory Procedures	Work with Animals, Autopsy, Cages	Aerob. Exp.	Handling, Transporting, Packaging Infectious Material	Wash, Clean, Sterilize Equipment Glassware	Repairing Building, Decon Room	Moving Heavy Objects	Other	Totals
Biological exposures	279(21)[a]	52(1)	304(1)	350(10)	205	128(2)		1	1319(35)
Lacerations	143(3)	163	33	12	53	29	8	26	467(3)
Contusions	38	7(1)	5	4	9	14	2	16	95(1)
Eye injuries	29	8	6	7	13	7		12	82
Burns	17(2)			1	22(1)	10(1)		6	56(4)
Strains and sprains	13	3	3(1)	3	2	4	20(2)	4	52(3)
Chemical exposures	26		4		16	3		3	52
Dermatitis	4	1			1	2			8
Fractures							1(1)		1(1)
Totals	549(26)	234(2)	355(2)	377(10)	321(1)	197(3)	31(3)	68	2132(47)

a. Parentheses denote number of lost-time accidents.

With the exception of eye injuries, a description of the nature of an accidental injury does not necessarily denote the location of the part of the body involved. The location of injured body parts not only provides useful preventive information but suggests causal factors that may be important. Partitioning of the Fort Detrick accident-involved people according to the nature of the injury and the involved body parts is shown in Table 71.

The conclusions drawn from this table are:

1) Biological exposures that involved the respiratory system (systemic) were the single most frequent type of accident.

2) Most lacerations (91 per cent) were on the arms, hands, and fingers.

3) The location of contusions was more evenly distributed, with 40 per cent occurring on the arms, hands, and fingers, 25 per cent on the legs, feet, and toes, and 35 per cent on the face or body trunk.

4) Burns occurred mostly on the arms, hands, and fingers (60 per cent) and on the legs and feet (29 per cent).

5) Most strains and sprains occurred to the back or body trunk (69 per cent).

6) Most accidents involving absorption of toxic chemicals were such that entrance was through the respiratory system.

To the extent that ratios of total to lost-time accidents reflect a measure of the relative risk of lost time when different body parts are involved, Table 71 shows the descending risk of lost time is (i) feet and toes, (ii) back, (iii) legs, (iv) abdomen and chest, (v) respiratory system, (vi) head and face, (vii) arms, (viii) fingers and thumbs, (ix) hands and (x) eyes.

C. ACCIDENTS CLASSIFIED ACCORDING TO MANNER OF CONTACT

The accident classification recommended by the American Standards Association[1] provides nine categories that describe accidents in terms of the manner in which the individual came in contact with the injurious substance or article. These categories are related to cause because they describe events occurring once an accident sequence has started. In any one accident, an understanding of the exact manner of contact is important in prescribing action to be taken to prevent recurrence. In summaries of accidents, statistics on the manner of contact are equally important in providing information about causal factors common to a number of accidents.

For use with laboratory accidents, the Z-16 classification was modified by addition of a category for injuries due to exposure to ultraviolet radiation.

The most common ways in which laboratory workers came in contact with injurious substances were by inhalation, absorption and ingestion, striking against, and being struck by. At three institutions these means of contact accounted for 60 per cent or more of the accidents. These distributions are shown in Table 72.

[1]"Compiling Industrial Accident Causes, Part I - Selection of Accident Facts," Z 16.2 (1941), American Standards Association, New York, pp. 9-10.

TABLE 71. LABORATORY ACCIDENTS CLASSIFIED ACCORDING TO NATURE OF INJURY AND BODY PARTS INVOLVED

Nature of Injury	Systemic	Fingers and Thumbs	Hands	Eyes	Arms	Head and Face	Legs	Back	Abdomen and Chest	Feet and Toes	Totals
Biological exposures	1297(35)[a]	1	3		3	2	2		11		1219(35)
Lacerations		320(2)	70		34(1)	21	15	2		5	467(3)
Contusions		23	3		12	20	14	7	7(1)	9	95(1)
Eye injuries				82							82
Burns		8	9		17	3(1)	6	3		10(3)	56(4)
Strains and sprains		2			6		6(1)	25(2)	11	2	52(3)
Chemical exposures	38	1	3		3	1	1		2	3	52
Dermatitis		1	3			1			2	1	8
Fractures							1(1)				1(1)
Totals	1335(35)	356(2)	91	82	75(1)	48(1)	45(2)	37(2)	33(1)	30(3)	2132(47)

a. Parentheses denote number of lost-time accidents.

TABLE 72. ACCIDENTS CLASSIFIED ACCORDING TO MANNER OF CONTACT

Manner of Contact	Fort Detrick (A)		CDC (B)		NIH[a] (C)	
	Number	Per Cent	Number	Per Cent	Number	Per Cent
Inhalation, absorption, ingestion	507(39)[b]	41.6	87(12)	27.4	287(55)	30.6
Striking against	361(3)	29.6	105(1)	33.0	145(16)	15.5
Struck by	187(1)	15.4	66(1)	20.6	134(15)	14.3
Slip or overexertion	47(3)	3.9	18(7)	5.7	110(40)	11.7
Contact, extreme temperatures	40	3.3	12	3.8	39(6)	4.1
Caught in or between	25	2.0	12(1)	3.8	58(15)	6.2
Contact, UV radiation	21	1.7	6(1)	1.9	13	1.4
Fall, same level	19	1.6	6(4)	1.9	122(23)	13.0
Fall, different level	6(1)	0.5	6(4)	1.9	26(8)	2.8
Contact, electric current	5	0.4	0	0	2	0.2
Totals	1218(47)	100.0	318(31)	100.0	936(178)	100.0

a. Includes "potentially serious" and lost-time accidents.
b. Parentheses denote number of lost-time accidents.

<u>Rank order correlation coefficients</u>

r (AB) = 0.94, "t" = 7.520*

r (AC) = 0.84, "t" = 2.865*

r (BC) = 0.89, "t" = 5.645*

*At df = 8 and at the 0.05 level of significance, the hypothesis that the population correlation is zero is rejected.

Although there was significant correlation at the three institutions concerning the manner in which contact was made with the injurious substance, there was little agreement in the relative seriousness of the accidents as indicated from the numbers of lost-time accidents in each category. Table 73 shows crude estimates of risk based on the ratios of lost-time to total accidents.

These data illustrate that some means of accident contact present greater than average risk of lost time and that these risks may not be the same at different institutions. It is to be noted that slips or overexertion and falls from different

TABLE 73. ESTIMATION OF RISK OF LOST TIME ACCORDING TO MANNER OF CONTACT

Manner of Contact	Ratio of Lost Time to Total Accidents		
	Fort Detrick	CDC	NIH
Inhalation, absorption, ingestion	1:13[a]	1:7[a]	1:5
Striking against	1:120	1:105	1:9
Struck by	1:187	1:66	1:9
Fall, same level		1:2[a]	1:9
Slip or overexertion	1:16[a]	1:3[a]	1:3[a]
Caught in or between		1:12	1:4
Contact, extreme temperature			1:7
Fall, different level	1:6[a]	1:2[a]	1:3[a]
Contact, UV radiation		1:6[a]	
Over-all ratios	1:26	1:10	1:5

a. Risk probably greater than average for that institution.

levels occupied high-hazard positions at all three institutions. Beyond this, it is also clear that inhaling, absorbing, or ingesting harmful substances is typically among the most frequently occurring types of laboratory accidents and presents high to average risk of lost time.

Females were present in the various manner-of-contact categories to an extent not different from their relative frequency in the exposed population.

Examination of the ages of the Fort Detrick employees allowed several significant observations. The distribution by age groups is shown in Table 74. For each group, "inhalation, absorption, and ingestion" was the most frequent manner of contact, producing the greatest proportion of the lost-time accidents. The five most frequent manners of contact were further treated in Table 75 to test the hypothesis that each age group was involved to an extent not different from its distribution in the total exposed population. For two methods of contact, "inhalation, absorption, or ingestion" and "striking against," the age-group distributions differed from the expected. People older than 50 were identified as having fewer than expected accidents involving inhalation, absorption, or ingestion; the 30- to 39- and the 40- to 49-year groups had more than expected. With "striking against" accidents, the 20- to 29-year group was more frequently involved than expected.

Previous data showed that the respiratory system (or systemic exposures) was the most frequently involved body part in Fort Detrick laboratory accidents. Table 76 identifies the body parts for accidents classified according to the nature of the

TABLE 74. AGES OF ACCIDENT-INVOLVED PEOPLE ACCORDING TO THE MANNER OF CONTACT

Manner of Contact	Number of Accident-Involved People in Indicated Age Group				
	20-29	30-39	40-49	50-59	> 60
Inhalation, absorption, ingestion	208(11)[a]	448(18)	247(6)	37(4)	17
Striking against	98	128(3)	66	17	10
Struck by	36	64	33(1)	6	9
Contact, extreme temperature	13	16	9	4	2
Slip or overexertion	8	21(1)	6(1)	3(1)	2
Caught in or between	6	6	5	0	2
Contact, UV radiation	2	9	7	0	0
Fall, same level	1	7	6	1	1
Contact, electric current	1	3	1	0	0
Fall, different level	1	2	2(1)	0	0

a. Parentheses denote number of lost-time accidents.

TABLE 75. ACCIDENT-INVOLVED PEOPLE COMPARED IN RELATION TO AGE GROUP AND MANNER OF CONTACT

Manner of Contact	Number of Accident-Involved People in Indicated Age Group								Chi Squares
	20-29		30-39		40-49		> 50		
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
Inhalation, absorption, ingestion	208	201	448	431	247	239	54	86	13.090[a]
Striking against	98	67	128	144	66	80	27	28	18.607[a]
Struck by	36	31	64	67	33	37	15	13	1.680
Contact, extreme temperature	13	9	16	20	9	11	6	4	3.942
Slip or overexertion	8	8	21	18	6	10	5	4	2.350

a. At df = 3 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

injury. For each "manner of contact," the most frequently injured part is easily identified. The conclusions derived from these data are:

1) Two-thirds of the accident-involved people contacted hazardous substances by inhalation, absorption, or ingestion. Of these, inhalation occurred most frequently.

2) Striking against objects was the second most frequent manner of contact, involving 17 per cent of the accident-involved people. Eighty-six per cent of these people suffered injury to their arms, hands, and fingers, with finger injuries the most frequent.

3) The third most frequent manner of contact was being struck by moving objects. Most of the "struck by" accidents (68 per cent) resulted in injury to the arms, hands, and fingers. Again, fingers were most frequently involved.

4) Injuries due to slipping or overexertion were next; most injuries (74 per cent) were in the back or body trunk area.

5) Contact with extreme temperatures was the fifth most frequent manner of contact, with 68 per cent of the injuries occurring to the arms, hands, and fingers.

6) Most "caught in or between" accidents resulted in finger injuries.

Table 77 shows the occupations of the Fort Detrick accident-involved people in relation to manner of contact. The skewed distribution in the direction of laboratory technicians and inhalation, absorption, and ingestion accidents is readily apparent. Likewise, inhalation, absorption, or ingestion by laboratory technicians was responsible for 55 per cent of the lost-time accidents. This occurred in spite of the fact that technicians comprised only 44 per cent of the total exposed population and inhalation, absorption, and ingestion is only one of ten possible means of contacting injurious substances.

Tasks being performed at the time of accidents are shown in Table 78. Inhalation, absorption, or ingestion accidents were frequent during most laboratory tasks. Most lost-time accidents occurred during routine diluting and plating procedures and during the handling, transporting, or packaging of infectious materials.

For laboratory infections and for biological accidents that present a risk of infection, the actual or probable manner of contact with infectious material can be classified according to how it enters or comes in contact with the body. This will be referred to as "mode of infection." Its classification is helpful in revealing the causes of biological accidents because it identifies points at which insufficient barriers were present to prevent contact with infectious materials. Moreover, for some modes of infection, the direct cause factors are apparent from the mode classification. For example, infection or exposure by the ingestion mode is usually a result of aspiration of infectious materials through a pipette, whereas direct inoculation is typified by syringe inoculation, cuts from glassware, and animal bites. Skin contamination is usually a result of spilling culture materials.

A review of approximately 250 publications on laboratory infections resulted in the classification of 921 cases.

From these data, it was evident that the cause factors that result in the inhalation of infectious aerosols or droplets are those that need the greatest amount

TABLE 76. BODY PARTS AFFECTED IN RELATION TO MANNER OF CONTACT

Manner of Contact	Head and Face	Eyes	Back	Abdomen and Chest	Arms	Hands	Fingers and Thumbs	Legs	Feet and Toes	Systemic	Totals
Inhalation, absorption or ingestion	5(1)[a]	38		15	6	8	4	2	8(3)	1335(35)	1421(39)
Striking against	24		4	1	22(1)	52	236(2)	17	5		361(3)
Struck by	15	24	1		21	19	88	9(1)	10		187(1)
Slip or overexertion			25(2)	10	6		1	5(1)			47(3)
Contact, extreme temperatures	1		3		14	7	6	5	4		40
Caught in or between						3	19	2	1		25
Contact, UV radiation	1	20									21
Fall, same level	2		4	5	3		1	4			19
Fall, different level				2(1)	1			1	2		6(1)
Contact, electric current					2	2	1				5
Totals	48(1)	82	37(2)	33(1)	75(1)	91	356(2)	45(2)	30(3)	1335(35)	2132(47)

a. Parentheses denote number of lost-time accidents.

TABLE 77. LABORATORY ACCIDENTS CLASSIFIED ACCORDING TO MANNER OF CONTACT AND OCCUPATION

Manner of Contact	Laboratory Technicians	Trained Scientific Personnel	Animal Caretakers	Dishwashers and Janitors	Workmen and Others	Totals
Inhalation, absorption, ingestion	988(26)[a]	247(7)	58(1)	20(1)	108(4)	1421(39)
Striking against	161	89(3)	37	30	44	361(3)
Struck by	77	29	60	6	15(1)	187(1)
Fall, same level	5	6	1	1	6	19
Slip, overexertion	15(1)	7	10(2)	5	10	47(3)
Caught in or between	11	4	3	2	5	25
Contact, extreme temperatures	25	2	1	4	8	40
Fall, different level	3(1)	1			2	6(1)
Contact, UV radiation	5	5	6		5	21
Contact, electric current	2				3	5
Totals	1292(28)	390(10)	176(3)	68(1)	206(5)	2132(47)

a. Parentheses denote number of lost-time accidents.

TABLE 78. LABORATORY ACCIDENTS CLASSIFIED ACCORDING TO MANNER OF CONTACT AND TASKS BEING PERFORMED

Manner of Contact	Routine Laboratory Procedures	Work with Animals, Autopsy, Cages	Aerobiological Experiments	Handling, Transporting, Packaging Infectious Materials	Wash, Clean, Sterilize Equipment Glassware	Repair Buildings, Decon Rooms	Moving Heavy Apparatus	Other	Totals
Inhalation, absorption, ingestion	382(21)[a]	57(2)	314(1)	252(11)	280(1)	116(3)		20	1421(39)
Striking against	77(3)	62	28	94	35	39	1	25	361(3)
Struck by	25	103	7	28	1	16	2(1)	5	187(1)
Fall, same level	5	1	2			3		8	19
Slip, overexertion	4(1)	3	2	2	5	3	23(2)	5	47(3)
Caught in or between	14	3	1			3	3	1	25
Contact, extreme temperatures	29		1			9		1	40
Fall, different level	1(1)			1			2	2	6(1)
Contact, UV radiation	10	5				6			21
Contact, electric current	2					2		1	5
Totals	549(26)	234(2)	355(1)	377(11)	321(1)	197(3)	31(3)	68	2132(47)

a. Parentheses denote number of lost-time accidents.

TABLE 79. MODE OF 921 LABORATORY INFECTIONS

Mode of Infection	Number	Per Cent
Inhalation	674	73.2
Ingestion	163	17.7
Direct inoculation	84	9.1
(Animal bites and cuts)	(59)	(6.4)
(Syringe inoculation)	(25)	(2.7)
Skin contamination	0	0
Total	921	100.0

of attention. The reasons for this have been discussed by Albrecht,[1] who emphasized the probable increased role of accidental aerosol infection due to increased number and more complicated laboratory manipulations and an increased interest in virological investigations. Of particular importance, according to Albrecht, is aerosol contamination of the laboratory environment with disease agents "...of a type which under natural circumstances are rarely or practically never transmitted by the atmospheric route." The seriousness of infection of laboratory personnel by the inhalation mode was thought by Albrecht to deserve particular attention because:

1) The formation of aerosols takes place unobserved and the particulates are invisible.

2) Aerosol-producing operations are often considered to be harmless.

3) Many laboratory workers "...believe that the customary safety measures afford adequate protection and are not aware of the fact that, due to the duration of flotation of the aerosol, infections may come about over a prolonged period of time."[2]

Actual or possible exposures to infectious materials were identified in almost 60 per cent of the Fort Detrick laboratory accidents. These were classified according to mode of exposure in Table 80.

It will be noted that, although inhalation was the mode in 44 per cent of the accidents involving infectious materials, these accidents were responsible for 84 per cent of the infections. Expression of these data in terms of ratios to depict relative risks of infection resulted in the following:

[1]J. Albrecht, "Danger Due to Infectious Aerosols in the Laboratory," Fort der Biologischen Aerosol-Forschung, 1957-1961, pp. 148-152, Friedrich-Karl Schattauer-Verlag, Stuttgart.

[2]Ibid., p. 148.

Mode	Ratio, Infectious to Total Accidents
Ingestion	1:1
Inhalation	1:9
Direct inoculation	1:67
Skin contamination	1:121

The significance of the above differences in ratios is found by comparing observed and expected inhalation infections with those observed and expected for the other three modes.

TABLE 80. MODE OF INFECTION OR EXPOSURE FOR FORT DETRICK ACCIDENTS

Mode of Infection or Exposure	Number of Accidents	Per Cent
Inhalation	310(32)[a]	44.2
Direct inoculation	269(4)	38.4
Skin contamination	121(1)	17.3
Ingestion	1(1)	0.1

a. Parentheses denote number of lost-time infections.

TABLE 81. OBSERVED AND EXPECTED MODES OF INFECTION

Mode	Number of Infections	
	Observed	Expected
Inhalation	32	16
Inoculation, ingestion, and skin contamination	6	22
Chi square	30.000[a]	

a. At df = 1 and at the 0.05 level of significance, the hypothesis of equal frequencies is rejected.

Although ingestion of cultures by mouth pipetting occurred only once, an infection resulted. With the other modes of exposure, inhalation presented the greatest risk of infection. This substantiates the view of Albrecht and of others who believe that aerosol contamination of the environment presents the greatest hazard to laboratory workers. The relative order of risk from spills that contaminate the skin appears to be low. However, this result must be interpreted carefully because:

1) Skin contamination can give rise to ingestion of microorganisms or to aerosol formation.

2) Some microorganisms are said to be capable of penetrating the unbroken skin.

As compared with the other modes, direct inoculation presents an intermediate level of hazard. It is probable that direct inoculation with syringe and needle is more hazardous as an infection cause than cuts from glassware and animal bites.

When the mode of infection or exposure of the Fort Detrick accidents was subdivided according to the age and occupation of the involved people and the tasks they were performing the results were not substantially different from analyses previously presented. The 20- to 30-year group and the over-50-year group had significantly more total accidents than expected, but the distribution of lost-time accidents was not different for the several age groups. Laboratory technical assistants had the largest share of these accidents and the majority of these were inhalation accidents. The most important single task associated with the accidents was the carrying out of routine laboratory procedures such as diluting and plating. Forty per cent of the inhalation accidents happened during routine laboratory procedures.

D. ACCIDENT AGENCIES

The "agency" of an accident is the object or substance most closely associated with the injury or exposure. It is further identified as the object or substance that should have been eliminated, guarded, modified, or contained.

For microbiological laboratory accidents three classes of accident agencies were considered: mechanical, biological, and chemical. Possible ways in which these agencies may relate to cause are:

1) Mechanical agencies — may be associated with accidents due to lack of guarding, improper use, improper design, or operational failure.

2) Biological agencies — association with accidents is primarily due to failure to contain or isolate the infectious material or failure to use the proper procedure or equipment.

3) Chemical agencies — likewise primarily associated with failure to contain harmful substances or to protect against them.

It should be emphasized that properly classified accident agencies are causally related: that is, if containment by or with the agency or its modification would have prevented an accident, then failure to contain or modify is an accident cause.

Chemical agencies were associated with approximately six per cent (72 of 1218) of the Fort Detrick accidents; four were associated with lost-time accidents. Most of the chemical agencies were toxic chemicals that were not properly contained or not effectively neutralized. Only two accidents involving flammable chemicals were identified and only eight accidents were associated with heated chemical solutions. Beta-propiolactone, ethylene oxide, and sodium hydroxide, all used as decontaminants, were the agencies most frequently associated with accidents involving chemical agencies. In most of these, chemical burns were produced by skin contact.

Mechanical agencies were associated to some degree with 95 per cent of the Fort Detrick accidents. Table 82 lists the various agencies and the number of accidents associated with each. Mechanical agencies were not identified for about five per cent of the accidents, but this group included 19 lost-time laboratory infections due to "unknown causes." Fifty per cent of the mechanical agencies were those common to microbiological work spaces such as glassware, containers, gloves, syringes, autoclaves, and ventilated cabinets.

In terms of the relative risk of causing loss of time, the following mechanical agencies, in the order presented, appear to be those of greatest concern:

Electrical apparatus	Laboratory glassware
Pipettes	Containers, cases, etc.
Ventilated cabinets	Animal cages and cage racks
Centrifuges	Syringes and needles
Building ventilation systems	Gloves.

It is interesting that "building ventilation systems" (or more precisely the failure of these systems) is the only agency in the above list that can be said to be consistently beyond the control of workers in the laboratory.

Regrouping of the mechanical agencies associated with lost-time accidents provided a means of testing the hypothesis that several categories of agencies were associated with lost-time accidents to an extent predictable from their association with non-lost-time accidents. For this analysis only the lost-time accidents known to be associated with mechanical agencies could be considered. As shown below, using the chi square statistic, insufficient evidence was available to reject the hypothesis.

Biological accident agencies were identified with approximately 50 per cent of the Fort Detrick accidents. The distribution for these accidents is shown in Table 84. The particular significance of these data is in their ability to demonstrate the relative hazards associated with the various forms of infectious materials. Thus, the 38 accidents associated with dried cultures resulted in 8 infections (a ratio of 1:5), whereas 375 accidents with liquid cultures resulted in the same number of infections (a ratio of 1:47).

Taking these ratios as an estimate of relative risk of infection, one obtains the following:

Biological Agency	Ratio, Infections to Total Accidents
Dried or lyophilized cultures	1:5
Infected eggs	1:6
Infected animal tissue or blood	1:6
Aerosolized cultures	1:17
Liquid cultures	1:47
Infected live animals	1:77

TABLE 82. MECHANICAL AGENCIES ASSOCIATED WITH FORT DETRICK LABORATORY ACCIDENTS

Agency	Number	Per Cent
Laboratory glassware	153(6)[a]	12.6
Containers, cases, etc.	105(4)	8.6
Gloves (all types)	101(2)	8.3
Syringes and needles	94(2)	7.7
Ventilated cabinets and cabinet systems	88(7)	7.2
Autoclaves and sterilizing chambers	82	6.7
Pipes, valves, plumbing	63	5.2
Animal cages and racks	45(1)	3.7
Electrical apparatus	33(3)	2.5
Laboratory hand tools	31	2.5
Non-powered shop tools	25	2.1
Ventilation systems	25(1)	2.1
Refrigerators and deep freezes	21	1.7
UV lamps	19	1.6
Centrifuges	16(1)	1.3
Autopsy instruments	13	1.0
Pipettes	12(1)	<1
Floors	10	<1
Stairs	10	<1
Powered shop tools	10	<1
Table tops or working surfaces	9	<1
Walls	7	<1
Ventilated personnel hoods and suits	7	<1
Conveyors	7	<1
Filter plenums	4	<1
Tissue grinders	4	<1
Sonic vibrators	3	<1
Elevators	3	<1
Other	164	13.5
Unknown	54(19)	4.4
Totals	1218(47)	

a. Parentheses denote number of lost-time accidents.

TABLE 83. OBSERVED AND EXPECTED AGENCIES OF LOST-TIME ACCIDENTS

Type of Mechanical Agency	Number of Lost-Time Accidents		Chi Square
	Expected[a]	Observed	
Glassware and glass apparatus	5.9	9	
Other laboratory instruments and apparatus	10.1	11	
Buildings and installed building equipment	12.0	8	3.042[b]

a. Based on frequency of mechanical agency types in minor accidents.
b. At df = 2 and at the 0.05 level of significance the hypothesis of equal frequencies is accepted.

TABLE 84. BIOLOGICAL AGENCIES ASSOCIATED WITH FORT DETRICK LABORATORY ACCIDENTS

Biological Agency	Number of Accidents	Per Cent
Liquid cultures	375(8)[a]	59.8
Infected live animals	77(1)	12.3
Aerosolized cultures	52(3)	8.3
Infected eggs	45(8)	7.2
Dried or lyophilized cultures	38(8)	6.0
Infected animal tissue or blood	17(3)	2.7
Frozen cultures	15	2.4
Infected tissue cultures	8	1.3
Totals	627(31)	100.0

a. Parentheses denote lost-time accidents.

The significance of the differences between these ratios is generally shown by the fact that the distribution of infections as observed for the six biological accident agencies is significantly different from that expected from the distribution of non-lost-time accidents, when measured by the chi square statistic.

E. CONCLUSIONS

Although accident causal factors are further studied in subsequent Sections, it is convenient, because of the bulk of the data presented, to summarize each chapter separately.

The following conclusions and observations are based largely on the Fort Detrick data, but supported in part by data collected from the literature and from other institutions.

In infectious disease laboratories, accidents not involving pathogenic materials constituted 50 per cent or more of the total number of accidents. Accidents with pathogens were typically responsible for one-third to one-half of the accidents. Biological accidents more often resulted in loss of work time than industrial accidents. Accidents that involved only biological materials without concurrent traumatic injury were far more serious than those in which the two components were combined. Typically, for all types of microbiological laboratory accidents, from 2.5 to 10.0 per cent resulted in lost-time injuries or infections.

In relation to their frequency in the exposed laboratory population, younger people with less technical training have more accidents than would be expected. Specifically, it was found that laboratory technical assistants and animal caretakers had about twice the expected number of biological accidents. Moreover, biological accidents occurred to the 20- to 29-year age group with greater frequency than to other age groups.

Female laboratory employees, on a relative basis, had fewer biological accidents than males, but had their expected share of injuries.

The most frequent laboratory tasks associated with biological accidents were (i) routine diluting and plating procedures, (ii) handling bulk quantities of infectious materials, (iii) performing aerobiological experiments, and (iv) exposing, injecting, or autopsying animals. Those tasks associated with most industrial laboratory accidents were (i) repairing or decontaminating laboratory rooms or buildings, (ii) washing, cleaning, or sterilizing equipment and glassware, (iii) working with animals, and (iv) setting up laboratory equipment and apparatus. The hazard level of various tasks varied considerably. Those relating to biological accidents were consistently more hazardous. Working with virus-inoculated eggs and routine diluting and plating were the most hazardous tasks.

Most biological accidents potentially or actually produced injury to the respiratory system. Most other accidents resulted in injury to the arms, hands, fingers, and thumbs, with fingers and thumbs being the most frequently involved. When all accidents were considered, the respiratory system was by far the body part in most danger of being affected by laboratory accidents. Therefore, a significant cause factor was the failure to contain microorganisms and/or the failure to prevent their entry into the respiratory system. Failure to use equipment to protect the upper appendages from injury was also an important cause.

In total frequency, lacerations, biological exposures, contusions, eye injuries, and burns were the most frequent types of laboratory accidents. However, lacerations only infrequently resulted in lost time; biological exposures frequently resulted in infection and lost time. Younger laboratory employees had more than their share of lacerations. Typical causal agencies for each of nine injury types were determined for two laboratory institutions. Laboratory technical assistants were identified as having more of most types of injuries than expected. Most lacerations occurred on the arms, hands, and fingers.

As expected, most laboratory employees came in contact with harmful or potentially harmful substances by inhalation, absorption, or ingestion, but inhalation was by far the most important and the most dangerous of the three. Striking against and being struck by were also important contact methods. Slipping or falling were high-hazard accidents, although they occurred less frequently than those above. Older employees (above 50 years) had fewer than expected accidents involving inhalation, absorption, or ingestion. Younger people (20 to 29 years) injured themselves by striking against objects more frequently than expected. Most inhalation, absorption, or ingestion accidents, including lost-time accidents, occurred to laboratory technical assistants while they were doing routine diluting and plating procedures (including working with eggs), or handling, transporting, or packaging infectious materials.

Classification of biological accidents according to actual or probable mode of infection confirmed that airborne contamination, with the resulting risk of inhalation of infectious materials, is the most frequent mode of laboratory exposure and results in the greatest proportion of laboratory infections. Moreover, these accidents usually occur during routine diluting and plating procedures. Although it seldom occurs, oral aspiration of infectious cultures is a serious accident.

The problem of "unknown" causes for laboratory infections was illustrated by the fact that mechanical agencies were not identified for 5 per cent of the accidents, but this 5 per cent contained 40 per cent of the lost-time accidents. Glassware, instruments and apparatus, and building structures and equipment were the most important mechanical agencies associated with the remaining lost-time accidents.

Analysis of biological agencies showed that dried or lyophilized cultures, infected eggs, and aerosolized cultures were the most hazardous forms of infectious microorganisms handled in the laboratory.

VI. LABORATORY ACCIDENT CAUSAL FACTORS—UNSAFE ACTS AND CONDITIONS

Previous consideration of accident classes, types, and agencies, together with data on other characteristics of laboratory accidents, constitutes the descriptive phase of accident analysis, providing information in terms of who, when, what, and where accidents occurred. Interrelationships among susceptible hosts, predisposing environments, and the involved agencies are further examined in this chapter by analysis of data on unsafe acts and unsafe conditions. In the epidemiological approach to the pathogenesis of accidents, interactions between the host and the agency and the host and the environment are obvious means of locating causes in an accident prevention effort. However, it is inevitable that more subtle relationships and interactions will appear that will provide important cause data. This has been explained by McFarland[1] as follows:

> The epidemiologic study of accidents may be considered analogous to the study of disease where the agents are known, but the causative associations and interrelationships in the host-agent-environment complex are not known. There is also the complication that many different kinds of agents acting in many different ways are involved. This suggests that strong associations (as opposed to those that are weak but reach statistical significance) will rarely be found. Those that would be useful in the development of specific hypotheses of causation are most likely to occur when attention is directed toward particular classes of accidents, in relation to particular segments of the population. Also, in the field of accidents, the development of causal hypotheses may be especially dependent on the piecing together of bits of knowledge from a variety of sources and disciplinary approaches.

The key word why is introduced with the classification of unsafe acts and unsafe conditions. Of course it must be recognized that these classifications represent consideration of accident causes only at an upper layer. This is because one may also ask why the unsafe acts were done or why the unsafe conditions existed. Carried to extremes one would find almost all accidents to be "man-caused" because, in most situations, man made the machine or created the work environment. Obviously, cause analysis must be taken only to that depth where it is practical and profitable to use the resulting data in the prevention of accidents.

The data in this Section are taken entirely from laboratory accident records at Fort Detrick. The classification categories for unsafe acts and unsafe conditions follow as closely as possible those recommended by the American Standards Association, but additional categories were added to cover work habits and equipment typical of microbiological laboratories.

A. UNSAFE ACTS

The records of investigation of 1218 laboratory accidents at Fort Detrick showed that "no unsafe acts" were involved in 229 accidents or 18.8 per cent. For an additional 153 accidents, or 12.6 per cent, the records indicated that unsafe acts had occurred but could not be specifically identified. Thus, known unsafe acts were identified in 880, or 72.2 per cent, of the Fort Detrick accidents.

Table 85 shows the number of unsafe acts in each category. Lost-time accidents are shown in parentheses. The importance of the unknown category is obvious because

[1]McFarland, R. A., "The Epidemiology of Accidents," in Accident Prevention, ed. by M. N. Halsey, (1961), McGraw-Hill Book Co., Inc., New York, p. 21.

it represents 12.6 per cent of the total number of accidents but contains almost 50 per cent of the lost-time accidents. An unsafe act was assumed to have been committed when no unsafe mechanical condition existed. In other words, it was assumed that each accident must have resulted from at least one unsafe act or unsafe condition. Therefore, those unsafe acts that were the most difficult to identify were responsible for a large segment of the lost-time occurrences. In fact, one in seven of the accidents with "unknown" unsafe acts resulted in lost time.

TABLE 85. UNSAFE ACTS IDENTIFIED WITH LABORATORY ACCIDENTS

Unsafe Acts	Number of Accidents	Per Cent
Handling equipment in an unsafe manner	330(4)[a]	27.0
Use of unsafe or improper equipment	167(2)	13.7
Failure to wear proper protective devices	92(5)	7.5
Operating at unsafe speeds	66(1)	5.4
Removing, altering, or not using safety equipment	32(3)	2.6
Performing operations prohibited by regulations	28(2)	2.3
Dropping cultures, tools, etc.	19	1.6
Failure to follow instructions	18	1.5
Failure to report unsafe conditions	18	1.5
Miscellaneous	66	5.5
Unknown	153(23)	12.6
None	229(7)	18.8
Total	1218(47)	

a. Parentheses denote lost-time accidents.

With the other categories of unsafe acts, the relative frequency of lost-time accidents did not constitute a constant percentage of the totals. Using ratios of lost-time to total accidents, estimates of the relative seriousness of most of the unsafe acts was obtained (Table 86).

In Table 87 the unsafe acts are classified according to the class of accidents they caused: industrial, biological, or combined.

TABLE 86. ESTIMATES OF THE RELATIVE RISK OF LOST TIME FROM UNSAFE ACTS

Unsafe Act	Ratio, Lost-Time to Total Accidents
Unknown	1:7[a]
Removing, altering, or not using safety equipment	1:11[a]
Performing operations prohibited by regulations	1:14[a]
Failure to wear proper protective devices	1:18[a]
Operating at unsafe speeds	1:66
Handling equipment in an unsafe manner	1:83
Use of unsafe or improper equipment	1:84
Over-all ratio	1:26

a. Probably greater than average in risk of lost time.

Of prime importance in Table 87 is the identification of the seriousness of unknown acts for biological accidents, those involving only pathogenic microorganisms. One in three of the biological accidents caused by unknown unsafe acts resulted in lost time. Also, the data reveal that most lost-time accidents in which there was no unsafe act were biological. These were mainly equipment or ventilation failures, not under the control of the laboratory personnel, that resulted in airborne escape of pathogenic forms.

With industrial accidents, the most serious type of unsafe act was removing, altering, or not using safety equipment, followed by (i) failure to wear proper protective devices, and (ii) handling equipment in an unsafe manner. With biological accidents, failure to wear proper protective devices, performing operations prohibited by regulation, and removing, altering, or not using safety equipment were important unsafe acts resulting in loss of time.

The biological and combined accidents in which the probable or actual mode of infection or exposure could be determined are classified in Table 88 according to the type of unsafe act. The data identify inhalation as the predominant mode of infection for unknown unsafe acts. This result is entirely plausible when one considers that research on laboratory techniques has shown how easily microorganisms are aerosolized into the workers' environment and the fact that such aerial contamination cannot be detected by sight, smell, or touch.

Table 88 also identifies recognized unsafe acts that caused laboratory infections. Of particular importance are the unsafe acts of failure to wear proper protective devices, performing operations prohibited by regulation, and removing, altering, or not using safety equipment.

TABLE 87. UNSAFE ACTS CLASSIFIED ACCORDING TO CLASS OF ACCIDENT

Unsafe Act	Industrial	Biological	Combined
Handling equipment in an unsafe manner	175(3)[a]	68(1)	87
Use of unsafe or improper equipment	62	74(1)	31(1)
Failure to wear proper protective devices	67(2)	15(3)	10
Operating at unsafe speeds	34	14	18
Removing, altering, or not using safety equipment	14(2)	15(1)	3
Performing operations prohibited by regulation	9	18(2)	1
Dropping cultures, tools, etc.		18	1
Failure to follow instructions	13	4	1
Failure to report unsafe conditions	5	11	2
Miscellaneous	31	28	7
Unknown	64	72(23)	17
None	89(1)	112(6)	28
Totals	563(9)	449(37)	206(1)

a. Parentheses denote number of lost-time accidents.

TABLE 88. UNSAFE ACTS CLASSIFIED ACCORDING TO MODE OF EXPOSURE OR INFECTION

Unsafe Acts	Inhalation	Direct Inoculation	Skin Contamination	Ingestion
Handling equipment in an unsafe manner	42(1)[a]	92	20	1
Use of unsafe or improper equipment	52(1)	35(1)	15	-
Operating at unsafe speeds	6	19	3	1
Failure to wear proper protective devices	8(1)	10(2)	6	-
Dropping cultures	12	1	7	-
Performing operations prohibited by regulation	13(1)	-	4	1(1)
Removing, altering, or not using safety equipment	9	4	5(1)	-
Miscellaneous	13	13	8	-
Unknown	59(22)	19(1)	10	-

a. Parentheses denote number of lost-time accidents.

Just as Table 88 dealt with accidents involving biological materials, Table 89 deals with the injury-producing laboratory accidents.

TABLE 89. UNSAFE ACTS CLASSIFIED ACCORDING TO THE NATURE OF THE INJURIES

Unsafe Acts	Number of People Receiving				
	Lacerations	Contusions	Eye Injuries	Burns	Strains and Sprains
Handling equipment in an unsafe manner	87	18	15	10(1)	10(2)
Use of unsafe or improper equipment	78(1)[a]	15	13	9	9
Failure to wear proper protective devices	25(2)	5	4	3(2)	3
Operating at unsafe speeds	18	4	3	2	2(1)
Removing, altering, or not using safety equipment	14	3(1)	3	2(1)	2
Performing operations prohibited by regulations	8	2	2	1	1
Dropping cultures, tools, etc.	5	1	1	1	0
Failure to follow instructions	9	2	2	1	1
Failure to report unsafe conditions	13	3	2	2	1
Miscellaneous	36	7	6	4	4
None	119	24	21	14	13
Total people	467(3)	95(1)	82	56(4)	52(3)

a. Parentheses denote lost-time injuries.

In this case the numbers of accident-involved people, rather than the numbers of accidents, are identified. Table 89 classifies the five most common types of injuries in relation to unsafe acts. Lacerations, the most frequent type of laboratory injury, are recognized as frequently resulting from handling equipment in an unsafe manner, from the use of unsafe or improper equipment, or from the failure to wear proper protective devices. These unsafe acts were also the major causes of the other injuries.

All of the lost-time injuries resulted from the first five of the unsafe acts listed in Table 89. In contrast to the information in Table 88, none of the unknown unsafe acts resulted in lost-time injury.

B. UNSAFE CONDITIONS

It is a basic concept of accident cause theory that both an unsafe condition and an unsafe act may contribute to the cause of an accident. Moreover, it is evident that more than one unsafe act and/or condition can contribute to the occurrence of an accident. Therefore, the classifications of unsafe mechanical and physical conditions considered below must be taken as those that were identified as being most closely related to the accidents. By definition, any event not associated with at least one unsafe act or condition is not properly classified as an accident.

Unsafe mechanical or physical conditions were detected for 777 of the 1218 Fort Detrick laboratory accidents, 63.8 per cent. Of these, 227 were due to unsafe conditions that obviously and directly arose from unsafe acts. The remaining 550 accidents were identified with unsafe conditions not directly due to unsafe acts by the involved persons. A listing of the unsafe conditions for the Fort Detrick laboratory accidents is shown in Table 90.

TABLE 90. UNSAFE CONDITIONS IDENTIFIED WITH LABORATORY ACCIDENTS

Unsafe Condition	Number of Accidents	Per Cent
Defective condition of equipment or apparatus	273(7)[a]	22.5
Hazardous process, operation, or arrangement	105(13)[b]	8.6
Unsafe dress or apparel	91(3)[b]	7.5
Unsafe design or construction of equipment or apparatus	64(2)	5.3
Inadequate guarding	[illegible]	1.4
Use of wrong type of equipment or apparatus	[illegible]1[b]	2.[illegible]
Inadequate or incorrect ventilation or air filtration	26(1)	2.1
Leaking or non-tight equipment	16	1.3
Inadequate or incorrect illumination	[illegible]	[illegible]
Inadequate or incorrect decontamination equipment	[illegible]	[illegible]
Miscellaneous	10[illegible](1)	8.[illegible]
None	441(20)	36.2

a. Parentheses denote number of lost-time accidents.
b. Unsafe conditions obviously arising from unsafe acts.

A significant finding from these data is that 36 of 47 lost-time accidents, or 77 per cent, had no related unsafe conditions or those unsafe conditions that were identified were obviously due to unsafe acts. This lends support to the hypothesis that unsafe acts were the primary cause of approximately three-quarters of the lost-time laboratory accidents. Data presented previously indicated that, although about three-quarters of all accidents were related to unsafe acts, a category of unknown unsafe acts had to be included with the lost-time accidents to account for 83 per cent of the total.

The five most common unsafe conditions and the ratios suggesting their relative degree of hazard for producing lost time are shown in Table 91.

TABLE 91. ESTIMATES OF THE RELATIVE RISK OF LOST TIME FROM UNSAFE CONDITIONS

Unsafe Condition	Ratio, Lost-Time to Total Accidents
Hazardous process, operation, or arrangement	1:8
Inadequate ventilation or air filtration	1.26
Unsafe dress or apparel	1:30
Unsafe design or construction of equipment or apparatus	1:32
Defective condition of equipment or apparatus	1:39

It is to be noted that only hazardous process, operation, or arrangement would be predicted to be of higher than average risk and that these ratios, when compared with those for unsafe acts, suggest the greater seriousness of the latter. Moreover, two of the five unsafe conditions obviously derive directly from unsafe acts.

Table 92 classifies the unsafe conditions in relation to the class of accident. Approximately 60 per cent of the industrial accidents happened in the presence of a recognized unsafe condition. Of these, 75 per cent were due to the first five conditions listed in Table 92. With biological accidents, unsafe conditions were identified for about 72 per cent, with the first five categories containing the bulk of these. However, 20 of 37 lost-time infections, or 54 per cent, were not related to identified unsafe conditions. Of the unsafe conditions existing prior to biological accidents, hazardous process, operation, or arrangement is again identified with a high risk of lost time.

Specific comment must be made regarding defective condition of equipment or apparatus. This category is difficult to investigate. For example, if a flask or centrifuge tube breaks during use, the person submitting the accident report may assume that the breakage was due to a defect. However, in some instances it is also possible that the breakage was due to improper heating of the flask or failure to balance the centrifuge tubes. When the apparatus or equipment is destroyed by the accident, the accident investigator has no way of knowing its previous condition. Thus, in relation to the other unsafe categories, the defective condition category may have a lower probability of accuracy.

TABLE 92. UNSAFE CONDITIONS CLASSIFIED ACCORDING TO CLASS OF ACCIDENT

Unsafe Condition	Accident Class		
	Industrial	Biological	Combined
Defective condition of equipment or apparatus	75(2)[a]	158(5)	34
Hazardous process, operation, or arrangement	43(4)	30(8)	38(1)
Unsafe dress or apparel	67(1)	15(2)	9
Unsafe design or construction of equipment or apparatus	43(1)	13(1)	9
Inadequate guarding	23	25	6
Use of wrong type of equipment or apparatus	17	10	4
Inadequate or incorrect ventilation or air filtration	14	12(1)	
Leaking or nontight equipment	1	14	
Inadequate or incorrect illumination	5	3	1
Inadequate or incorrect decontamination equipment		5	1
Miscellaneous	46(1)	40	17
None	229	124(20)	88
Totals	563(9)	449(37)	206(1)

a. Parentheses denote number of lost-time accidents.

Unsafe conditions related to biological and combined accidents are listed in Table 93 in relation to the mode of exposure or infection.

Data in Table 93 explain further the finding from Table 92 that unsafe conditions were not found in 20 of 38 lost-time biological or combined accidents (infections). Table 93 also makes it clear that 19 of the 20 infections were ones in which the individuals became infected by breathing infectious microbial aerosols. Of the remaining inhalation infections, most were identified with defective condition of equipment or apparatus or hazardous process, operation, or arrangement. The hazard level of the latter category was high; one in every four accidents resulted in infection.

Table 94 deals with the unsafe conditions associated with the five most common types of injuries occurring in the laboratory. Approximately 32 per cent of the lacerations were associated with defective equipment, although none of these

TABLE 93. UNSAFE CONDITIONS CLASSIFIED ACCORDING TO MODE OF EXPOSURE OR INFECTION

Unsafe Condition	Inhalation	Direct Inoculation	Skin Contamination	Ingestion
Defective condition of equipment or apparatus	117(5)[a]	44	30	
Hazardous process, operation, or arrangement	25(6)	30	12	1
Unsafe dress or apparel	12(1)	9(1)	3	
Unsafe design or construction of equipment or apparatus	11	8	3(1)	
Inadequate guarding	13	7	11	
Use of wrong type of equipment or apparatus	7	4	3	
Inadequate or incorrect ventilation or filtration	10(1)		4	
Leaking or nontight equipment	10		4	
Inadequate or incorrect illumination	3	1		
Inadequate or incorrect decontamination equipment			4	
Miscellaneous	22	20	13	1
Other	78(19)	108(1)	25	2

a. Parentheses denote number of lost-time accidents.

resulted in loss of time. The condition most frequently associated with lost-time injuries was "hazardous process, operation, or arrangement." Note also that unsafe conditions were listed for all of the lost-time injuries, although, in Table 93, it was shown that unsafe conditions were seldom identified with the laboratory infections.

The data presented above show that unsafe conditions were identified with a majority of the laboratory accidents but that a disproportionately large number of lost-time accidents were included in the accidents not identified with unsafe conditions. Moreover, it was established that most of the no-unsafe-condition accidents were biological accidents in which infectious microorganisms were inhaled. Further information on these accidents was sought by determining what unsafe acts had been committed by persons who had accidents for which no unsafe conditions were identified. These data are shown in Table 95.

TABLE 94. UNSAFE CONDITIONS CLASSIFIED ACCORDING TO THE NATURE OF THE INJURIES

Unsafe Conditions	Number of People Receiving				
	Lacerations	Contusions	Eye Injuries	Burns	Strains and Sprains
Defective condition of equipment	149	30	26	18(1)	17
Hazardous process, operation, or arrangement	38(2)[a]	8(1)	6	5(2)	4(1)
Unsafe dress or apparel	26(1)	5	5	3(1)	3
Unsafe design or construction of equipment	10	2	2	1	1(1)
Inadequate guarding	18	4	3	2	2
Use of wrong type of equipment	10	2	2	1	1
Inadequate or incorrect ventilation or air filtration	10	3	2	1	1
Leaking or nontight equipment	10	2	2	1	1
Inadequate or incorrect illumination	5	1	1	1	1
Inadequate or incorrect decontamination equipment	3	1	1	1	0
Miscellaneous	44	9	8	5	5(1)
None	144	28	24	17	16
Total injured persons	467(3)	95(1)	82	56(4)	52(3)

a. Parentheses denote number of lost-time injuries.

It is of particular significance that all of the lost-time accidents in Table 95 resulted from unknown unsafe acts. Table 93 identifies these as infections rather than injuries. The actual but non-identified causative unsafe acts are viewed by the investigator as being transient mal-manipulations with test tubes, flasks, beakers, syringes, pipettes, inoculating loops, etc., in which the act resulting in the microorganisms' escape may have occurred in a fleeting second and may or may not have been noticed or remembered by the laboratory worker and may have been completely unknown to others. Several examples may be cited:

1) A film of culture on an inoculating loop broke.

2) A micro-drop of fluid escaped from the tip of a pipette or syringe.

TABLE 95. UNSAFE ACTS IDENTIFIED WITH ACCIDENTS HAVING NO UNSAFE CONDITIONS

Unsafe Acts	Number of "No-Unsafe-Condition" Accidents
Handling equipment in an unsafe manner	203
Failure to wear proper protective devices	5
Operating at unsafe speeds	29
Removing, altering, or not using safety equipment	6
Performing operations prohibited by regulation	9
Dropping cultures, tools, etc.	10
Failure to follow instructions	10
Failure to report unsafe conditions	3
Miscellaneous	11
Unknown	139(20)[a]

a. Parentheses denote number of lost-time accidents.

3) Unnoticed, a drop of culture ran down the outside of a test tube or flask.

4) Surface bubbles broke when a culture was stirred.

5) A worker was unaware that he placed his contaminated finger or pencil in his mouth.

6) A cigarette placed on the bench top served as a fomite for the transfer of infectious microorganisms to the mouth of the smoker.

These unsafe acts are put in their proper perspective when it is realized that a few or hundreds or even thousands of infectious microorganisms may be transferred or allowed to escape by these acts and when note is made of the small human infectious dose for a number of diseases.

Next, the unsafe acts related to the accidents that had unsafe conditions were tabulated as shown in Table 96.

Defective equipment in the absence of unsafe acts was the cause of about 10 per cent of the total accidents and 10 per cent of the lost-time accidents. The unsafe acts for accidents involving a hazardous process or arrangement appear particularily hazardous, as shown by the low ratios of lost-time to total accidents. For example, during a hazardous process, both instances of removing and of not using the safety equipment resulted in infection. Likewise, during hazardous processes, acts prohibited by regulation and the use of improper equipment each resulted in accidents that resulted in lost time two out of five times.

TABLE 96. UNSAFE ACTS IDENTIFIED WITH ACCIDENTS RELATED TO TWO UNSAFE CONDITIONS

Unsafe Acts	Number of Accidents Identified With: Defective Condition of Equipment	Hazardous Process, Operation, or Arrangement
Handling equipment in an unsafe manner	20	17(3)[a]
Use of unsafe or improper devices	83	5(2)
Failure to wear protective devices	3(1)	7(1)
Operating at unsafe speeds	6	10
Removing, altering, or not using safety equipment	1	2(2)
Performing operations prohibited by regulation	1	5(2)
Dropping cultures, tools, etc.	-	2
Failure to follow instructions	-	2
Miscellaneous	10	7
None	120(5)	34(1)

a. Parentheses denote number of lost-time accidents.

Table 97 presents an analysis of unsafe mechanical and physical conditions associated with lost-time accidents. Expected numbers were derived from the relative number of non-lost-time accidents in each category. The chi square value allows rejection of the hypothesis of equal frequencies, and the high-risk level of hazardous process, operation, or arrangement is again evident. Also, it is noteworthy that the number of lost-time accidents not related to unsafe conditions was closely predicted by the number of non-lost-time accidents in that category.

TABLE 97. UNSAFE CONDITIONS ASSOCIATED WITH LOST-TIME LABORATORY ACCIDENTS

Unsafe Mechanical or Physical Condition	Number of Lost-Time Accidents: Expected[a]	Observed	Chi Square
Defective equipment or apparatus	10.0	7	
Hazardous process, operation, or arrangement	4.5	13	
Other	14.3	7	
None	18.2	20	20.861[b]

a. Based on unsafe mechanical and physical conditions associated with non-lost-time accidents.

b. At df = 3 and at the 0.05 level of significance, the hypothesis of equal frequencies is rejected.

C. CONCLUSIONS

In this Section Fort Detrick data were used to evaluate the importance of unsafe acts and conditions in causing laboratory accidents. Categories of unsafe acts and conditions were identified and special attention was given to resultant classes and types of accidents. Moreover, the interrelationships of unsafe acts and unsafe conditions were investigated.

Unsafe acts were associated with more than three-quarters of the laboratory accidents. Handling equipment in an unsafe manner was the single most frequently occurring unsafe act, followed by use of unsafe or improper equipment, failure to wear proper protective devices, and operating at unsafe speeds. Thirteen per cent of the accidents were classified as caused by unknown unsafe conditions. However, one-half of the lost-time accidents were in this group. Therefore, it is concluded that the unsafe laboratory acts that are the most difficult to identify are those that are the most serious in producing lost-time accidents. Other unsafe acts that appeared to be greater than average in risk of lost time were:

1) Removing, altering, or not using safety equipment.

2) Performing operations prohibited by regulations.

3) Failure to wear proper protective devices.

Most of the unknown unsafe acts were identified with accidents involving infectious materials. Moreover, these were mostly accidents in which the actual or most probable mode of infection was by the inhalation of infectious microbial aerosols. That such aerosols are not readily detected by visual or other means explains why the unsafe acts producing them are frequently classified as unknown. Thus, failure to identify unsafe conditions for a number of accidents has, in this study, by process of elimination, aided in the construction of a realistic hypothesis to explain the causes of unknown laboratory infections.

Lacerations, contusions, and eye injuries, the three most frequent types of laboratory injuries, were associated most frequently with the unsafe acts of handling equipment in an unsafe manner and use of unsafe or improper equipment. Although unknown unsafe acts were identified with injury-producing accidents, none of these created loss of time.

The analyses in this Section show that unsafe acts and unsafe conditions did not exist as mutually exclusive accident causal factors; 64 per cent of the laboratory accidents were associated with recognized unsafe mechanical or physical conditions, but one-third of these were conditions directly resulting from unsafe acts. The greater importance of unsafe acts, as compared with unsafe conditions, was demonstrated by the fact that 77 per cent of the lost-time laboratory accidents were not caused by unsafe conditions other than those that arose directly from unsafe acts. Most of these, 66 per cent, were laboratory infections.

The most important unsafe conditions causing laboratory accidents were:

1) Defective condition of equipment or apparatus.

2) Hazardous process, operation, or arrangement.

3) Unsafe dress or apparel.

4) Unsafe design or construction of equipment or apparatus.

Although defective condition was the single most frequently identified unsafe condition, hazardous process, operation, or arrangement was the only one shown to be greater than average in risk of causing loss of time. Moreover, because of the difficulty in checking the previous condition of laboratory apparatus and equipment broken accidentally, it is suspected that the records reflect an over-emphasis on the importance of defective condition of equipment or apparatus. However, hazardous process, operation, or arrangement was identified as a high-hazard condition associated with laboratory infections acquired by inhalation of infectious microbial aerosols. This unsafe condition also was the most frequent causal factor associated with lost-time injuries.

Separate examination of the laboratory accidents not associated with unsafe conditions showed that all the lost-time accidents thus classified also had unknown unsafe acts. These were further identified as infections. This added information supports the hypothesis that unknown unsafe acts did indeed exist and that they are transient mal-manipulations with laboratory equipment and infectious microorganisms. These produce infection primarily by creating infectious microbial aerosols that, in general, remain undetected or are forgotten by the laboratory employee. Several examples were given.

Combined analyses also revealed that equipment failure in the absence of unsafe acts was the primary cause of 10 per cent of all the laboratory accidents as well as 10 per cent of the lost-time accidents.

Finally, it was shown that, although the number of lost-time accidents having no unsafe causal conditions could be closely predicted by the non-lost-time accidents in that category, hazardous processes or arrangements resulted in three times the expected number of lost-time accidents.

VII. HUMAN FACTORS IN LABORATORY ACCIDENT CAUSATION

A. ACCIDENT CASES

The following accident cases collected by the author illustrate human factors problems encountered in infectious disease laboratories.

Case 1. A scientist started centrifuging a mouse brain suspension of a human virus. She did not use the available safety cup as required by the regulations. As the centrifuge reached speed she heard a tube break and shatter in the bowl. She shut off the machine, opened the centrifuge and watched the rotor come to a halt. Then she started picking up the contaminated broken glass. A technician came in to help. The Safety Officer came into the room at this time, found out what had happened, ordered everyone out of the room, and placed a Keep Out sign on the door. While the Safety Officer was in another room questioning the scientist and technician another worker ignored the sign on the door, entered the room, and started centrifuging another organism in the same centrifuge which at that time had not been decontaminated and whose bowl was still wet with the spilled virus suspension.

To prevent possible infections everyone involved was given immune serum. The laboratory director had a talk with everyone about safety procedures.

Case 2. A laboratory technician dropped a syringe containing a culture of tubercle bacilli. It caught in the lower part of his laboratory coat but he thought that his leg had not been stuck and did nothing about it. Nevertheless the man developed a tuberculoma on his upper leg and spent six months in the hospital.

Case 3. A 16-year-old boy was hired to work in the dishwashing room in a laboratory in which smallpox virus was being used. It was the practice to vaccinate all department members every two years. The boy began work and was then given a note for his father to sign giving permission for the vaccination. His father refused. Several weeks elapsed before the father finally gave his permission. During this time the boy continued to work. A few days after the vaccination the boy became sick and his father phoned the laboratory. The director thought it was a reaction from the vaccination. It was subsequently determined that he had a mild case of smallpox and variola virus was isolated. Investigation showed that the boy had probably become infected from contaminated glassware taken from a cart containing material to be autoclaved. The boy slept, during part of his illness, with a younger brother who developed a very severe case of smallpox.

Obviously at least two mistakes were made that led to the infection. First, people should be vaccinated before beginning work in the laboratory. Second, it is obvious that there was not adequate separation and control of infectious and non-infectious materials.

Case 4. A scientist who had been in charge of a smallpox vaccine laboratory for ten years forgot to immunize a new employee. The employee developed a lesion on his forearm where his arm had touched the inoculated abdomen of a cow.

Case 5. Severe allergic reactions were experienced by a scientist in a tuberculosis laboratory. Each incident was preceded by the performance of a technique that involved centrifugation of dead tuberculosis organisms. After three allergic attacks, the laboratory director realized they were from breathing aerosols created during the centrifuging operation. A cabinet was designed for the centrifuge.

Case 6. A university professor gave one of his students an old, dried slant culture of *Bacillus anthracis* and told him to try to recover viable organisms. Several days later in looking at some colonies of another organism on blood agar, he noticed typical anthrax colonies outside the streaked area of the plate. Mouse injection proved the contaminant to be *B. anthracis*. Investigation revealed that when the technician had been given the culture he had filled the test tube to the brim with broth and then mixed with an inoculating loop. The hollow metal handle of the inoculating loop had taken up some of the contaminated fluid. Subsequently, when the loop was heated, the fluid in the handle became hot and sprayed out, contaminating the air and the plate being streaked.

Case 7. Sputum specimens were being processed by the acid digestion method for recovery of tubercle bacilli. Acid had been spilled into the brass centrifuge cups and a hole had corroded through the bottom of one of them. While the centrifuge was in operation a glass tube containing a specimen broke, and the hole in the brass cup allowed the culture to spray into the room. Two persons who were in the room at that time received massive respiratory infections.

Case 8. A virologist was injecting an animal with cowpox virus when the needle came off the syringe and the culture sprayed into his right eye. A severe infection followed that left him with impaired vision in that eye. During his one-month hospitalization, the virus was twice isolated from the eye.

When working with Russian spring-summer encephalitis virus, the same person had twice accidently inoculated himself. He was ill for a short while after one such accident and he now has a significant serum titer.

Case 9. A laboratory director was asked if there had been any laboratory illnesses among workers at his institute. He replied that as long as he had been there he recalled only two laboratory infections. These occurred between 1920 and 1930. One was a syphilitic infection of the finger resulting from a self-inoculation. The other was a case of diphtheria following aspiration of a culture through a pipette. After several minutes of discussion the assistant director spoke up and said, "Oh yes, we have had two cases of brucellosis in the last two years." The causes were not determined.

Then the director said that he had forgotten about the laboratory epidemic in 1947 in which there were 15 cases of Q fever among workers throughout the building. Recovery was satisfactory in all cases except for the director himself who, following the infection, suffered from pulmonary impairment for three years. No investigation of the Q fever infections was conducted. The worker who was thought to be responsible left a short time later. The director and his assistant stated that the laboratory man was a "sloppy worker" and that they assumed that he had been centrifuging or grinding tissue.

Further conversation prompted the director to remember that there had been some tuberculosis infections. In fact there had been five infections resulting in two fatalities. One of the cases was the director's wife, who had an eye infection and, as a result, has impaired vision in that eye. Three of the five cases brought suit and were awarded compensation payments. Apparently the infections resulted from experiments in which guinea pigs were being exposed in a crude device to aerosols of tubercle bacilli. No specific investigation was conducted.

Case 10. During his youth, this scientist had rheumatic fever. Eighteen years later he had a recurrence of the disease following a pipetting accident in which he had sucked a culture of staphylococci into his mouth. This made him aware of the hazards of pipetting. Now a laboratory director, this scientist will not hire non-professional people with a history of rheumatic fever.

B. ATTITUDES OF LABORATORY EMPLOYEES

A study of Fort Detrick employees conducted by the Adjutant General's Office of the Department of the Army[1] provided the only published data available for examining the attitudes of microbiological laboratory workers about safety. A questionnaire was submitted to 931 Fort Detrick workers, 540 laboratory personnel and 391 craft workers. The answers to the 48 questions in the questionnaire were analyzed according to the position of each person in the organization and his degree of satisfaction with working conditions. However, the analyses did not include comparison of laboratory and professional workers with craft workers. Although the Fort Detrick craft workers spend a portion of their time in infectious disease facilities, the nature of their work is sufficiently different to justify comparing laboratory and craft workers in their response to the attitude questionnaire. The responses to each question were reevaluated by the author by comparing these two groups. Because the number of questionnaires processed covered a large percentage of the laboratory workers and almost all of the craft workers, it was not possible to use sampling statistics in the treatment of data. However, in order to provide a realistic basis for statements concerning the attitudes of laboratory workers in relationship to the comparison group, only the largest differences in response are considered in the following analyses.

The 48 questions in the questionnaire were grouped into 10 categories, each consisting of two to ten questions. The responses to the questions in each category are discussed below.

1) Questions on background, family, social, and personal feelings:

The average age of the laboratory workers was less than that of the craft workers. This is explained by the fact that, as a group, the craft workers had worked at Fort Detrick longer than the laboratory workers. Also, a larger proportion of the laboratory workers were single. There was little difference in the way the two groups rated satisfaction with working conditions, their feelings about social and recreational activities at Fort Detrick, and in their answer to the question, "If you were starting all over, would you work at Fort Detrick again?" The groups did not differ in the degree to which their wives or families approved or disapproved of Fort Detrick as a place to work. However, there was a large difference in the educational level of the two groups. Table 98 summarizes the results of the questions in this category.

[1]"Attitudes Toward Safety at the Biological Warfare Laboratories," Operation Evaluation Report, PMB Report 48-58-A, Personnel Management Branch, The Adjutant General, Dept. of the Army, 1959. 73 pp.

TABLE 98. RESPONSES TO BACKGROUND, FAMILY, SOCIAL, AND PERSONAL QUESTIONS

Question Item	Value or Per Cent	
	Craft Workers	Laboratory Workers
Average age	39.4	35.8
Average years of service	7.9	6.8
Per cent single	5%	18%
Satisfied with working conditions	92%	94%
Negative opinion about increased social and recreational affairs	28%	29%
Would start all over again at Fort Detrick	60%	70%
Wives or family approve of Fort Detrick	61%	64%
College degree	0%	64%

2) Questions about supervisors:

Eight questions were asked about supervisors. With most questions there was little difference between the responses of craft workers and those of the laboratory workers; a majority in both groups stated that their supervisor (i) was fair to all employees, (ii) assumed his proper responsibility, (iii) kept his promises, (iv) kept employees informed, (v) gave credit where credit was due, (vi) set a good safety example, and (vii) stopped unsafe short cuts when he saw them. However, in the reporting of minor accidents, the craft workers, as compared with the laboratory workers, felt that their supervisors were more conscientious. Table 99 summarizes the results of these questions.

3) Questions about safety rules and regulations:

The responses by laboratory people were substantially different from those of the craft workers in three of five questions. The craft workers had a higher regard for the rules and regulations and were more certain that strict adherence to them would improve safety without creating other undesirable situations. There was no difference between the two groups' responses to questions regarding the uniformity of application of the safety regulations to different people and in different areas. These results are summarized in Table 100.

4) Questions about work habits of co-workers:

The three questions in this category were not answered differently by the two groups. Most people felt that their co-workers were safety-conscious, but would have disapproved of their co-workers' being careless about following the regulations. The responses of the two groups were the same in a question listing possible reasons why some workers ignore safety regulations.

TABLE 99. RESPONSES TO QUESTIONS ABOUT SUPERVISORS

Question Item	Per Cent	
	Craft Workers	Laboratory Workers
Supervisor always or usually:		
Is fair	81	90
Assumes his responsibilities	87	95
Keeps promises	82	96
Keeps us informed	71	70
Gives credit where credit is due	67	78
Sets a good example	66	62
Supervisor always stops short cuts	68	63
Supervisor always encourages reporting minor accidents	64	49

TABLE 100. RESPONSES TO QUESTIONS ABOUT SAFETY RULES AND REGULATIONS

Question Item	Per Cent	
	Craft Workers	Laboratory Workers
Safety would be improved if some rules were eliminated	15	28
If everyone obeyed the regulations:		
Everyone would be better protected	23	18
There would be fewer accidents	18	14
My job would be more difficult	1	4
There would still be unavoidable illnesses	10	15
I learned about safety rules from:		
Written materials	48	41
Lectures	13	7
Oral instructions	26	38
Common sense	13	9
"Couldn't say" if rules are followed in other areas	50	47
"Couldn't say" if other areas have rules that should be followed in my area	48	45

5) Questions about accident reporting:

There were three questions in this group. The first related to the proportion of accidents the respondents felt were reported. Approximately 75 per cent of both groups felt that one-half or more of the accidents were reported. From 62 to 66 per cent felt that "almost all" accidents were reported. There was a difference between the two groups in their feelings about the probable result of better reporting. The craft workers, to a greater extent than the laboratory workers, felt that more complete reporting would uncover additional causes of infections. In another question, in which respondents could check a number of factors resulting from good reporting, there was no difference between the answers of the two groups when judged on a positive vs. negative attitude basis. These results are shown in Table 101.

TABLE 101. RESPONSES TO QUESTIONS ABOUT ACCIDENT REPORTING

Question Item	Per Cent	
	Craft Workers	Laboratory Workers
One-half or more of all accidents are reported	79	75
"Almost all" accidents are reported	66	62
With better reporting 1/2 or more of the unknown causes would be known	57	46
With better reporting only 1/3 or less of the unknown causes would become known	12	23
Positive benefits would result from reporting each accident	73	67

6) Questions about the frequency and causes of accidents:

There was little difference in the responses of the two groups on two questions in which they were asked to select causes of illnesses and incidents. The responses to these questions are shown in Table 102. The two groups reacted in a different manner when asked about the probable significance of "accidents that don't seem to be important when they happen" in bringing about infectious diseases. Craft workers more readily agreed (81 per cent) that seemingly insignificant accidents may have important consequences than did the laboratory workers (68 per cent). This result is surprising in view of the more intimate contact of laboratory workers with laboratory procedures and techniques, but could probably be accounted for by more effective safety training to craft workers.

7) Questions about safety procedures and equipment:

Six per cent of the laboratory workers and none of the craft workers felt that there was too much equipment; 26 per cent of the craft workers as compared

TABLE 102. RESPONSES TO QUESTIONS ON ACCIDENT CAUSES

Question Item	Response, per cent	
	Craft Workers	Laboratory Workers
What do you think is the most common cause of the illnesses picked up in the Biological Laboratories?		
Unavoidable dangers on the job	14	17
Protection equipment was OK but failed to work	7	5
Protection equipment not good enough	4	6
Carelessness of workers	28	34
Lack of training	6	6
Poor attitude toward safety	10	9
Poor supervision	6	3
I don't know	25	20
Check any of the statements below that you feel describe the causes of the incidents:		
Safety equipment broke down or wasn't operating properly	11	13
Safety equipment was not good enough	6	5
Someone was negligent	19	14
Someone merely had an accident	22	22
Someone was working unsafely because of lack of training	7	7
I have experienced no incidents of this type	34	36
Other	1	3
"Accidents that don't seem to be important when they happen often bring about infectious diseases."		
I agree	81	68
I disagree	19	32

with 17 per cent of the laboratory workers felt that there was not enough equipment. The majority of both groups felt that the amount was about right.

Relative to the quality of the safety equipment, more craft workers than laboratory workers felt that improvements were needed; a greater percentage of the laboratory workers felt that the quality was better than necessary. The groups also differed in their feeling about how frequently surfaces, equipment, and rooms should be disinfected, the craft workers being inclined to specify more frequent disinfection. These responses are shown in Table 103.

TABLE 103. RESPONSE TO QUESTIONS ON SAFETY PROCEDURES AND EQUIPMENT

Question Item	Response, per cent	
	Craft Workers	Laboratory Workers
How do you feel about the safety equipment that is available for your use?		
There is too much equipment	0	6
The amount of equipment is about right	74	77
There is too little equipment	26	17
Concerning the safety equipment you use in your daily work, with which of the following statements do you agree?		
The quality needs improvement	41	30
The quality is about right	58	64
The quality is better than necessary	1	6
How often do you feel that working surfaces, equipment, and labs should be thoroughly disinfected?		
More frequently than it is done	52	35
About as frequently as it is done	47	64
Less frequently than it is done	1	1

8) Questions about safety personnel and safety organizations:

There were no differences in the responses of the two groups to 4 of 5 questions in this category. The majority of each group felt that (i) safety personnel were fair in their dealings, (ii) safety personnel were effective in their work, (iii) the Laboratory Safety Council was effective in improving safety, and (iv) safety lectures and conferences were effective in improving safety. However, the craft workers had a better opinion of the effectiveness of the Post Safety Council in improving work safety. These results are summarized in Table 104.

9) Questions about medical care and immunization:

Two questions were asked in this category. Regarding the effectiveness of immunization procedures, there were no large differences between the responses of the two groups, a majority of each felt that immunizations were effective. However, with regard to reporting to the Fort Detrick physician in case of illness, as required by regulation, the craft workers seemed more willing to follow the recommended procedure than did the laboratory group. The results of these questions are shown in Table 105.

TABLE 104. RESPONSES TO QUESTIONS ABOUT SAFETY ORGANIZATIONS AND PERSONNEL

Response	Response, per cent	
	Craft Workers	Laboratory Workers
Safety personnel are fair and just	68	69
Safety personnel are effective in their work	77	72
Laboratory Safety Council is effective	75	68
Safety lectures and conferences are effective	81	71
Post Safety Council is effective	81	65

TABLE 105. RESPONSES TO QUESTIONS ON MEDICAL CARE AND IMMUNIZATION

Question Item	Response, per cent	
	Craft Workers	Laboratory Workers
Do you feel that the immunization program shots are effective?		
Yes	72	66
No	6	12
Undecided	22	22
What would you do if you did not feel well and suspected an infection?		
I would report to Special Procedures immediately	92	83
I would wait, if symptoms persist report to Special Procedures	5	14
I would go to my own doctor because I don't like waiting at Special Procedures	1	1
I would go to my own doctor because Special Procedures might refuse to give me any more immunization	0	1
I would go to my own doctor because I lack confidence in Special Procedures	2	1

10) Questions about safety hazards and exposure levels:

The response of the craft and laboratory groups did not differ with respect to the type and frequency of infectious agents they were exposed to. Forty-three per cent of the craft workers and 45 per cent of the laboratory workers indicated that they felt that the infectious agent they were exposed to was the most dangerous at Fort Detrick. Moreover, 41 per cent of both groups indicated that within the past 12 months they had been unnecessarily exposed to an infection one or more times. Although it is difficult to explain the results of these two questions, it can be expected that the laboratory workers may have had a more knowledgeable basis for their answers than the craft group. With regard to taking short cuts or deliberate risks, it was clear that the laboratory workers were more prone to feel that risk-taking was occasionally necessary or justified. A greater proportion of the laboratory workers as compared with the craft workers agreed with the statement that Fort Detrick "is a safe place to work." Questions in this category are summarized in Table 106.

TABLE 106. RESPONSES TO QUESTIONS ON SAFETY HAZARDS

Question Item	Per Cent	
	Craft Workers	Laboratory Workers
Exposed to the most dangerous agent at Fort Detrick	43	45
Exposed to an average agent	34	39
In past year I had one or more unnecessary exposures to infection	49	49
Fort Detrick is a safe place to work	30	66
Short cuts or deliberate risks are occasionally justified	9	26

Malfetti[1] has defined an attitude as

> ...an accumulation of information and experience that predisposes an individual to certain behavior. In this sense, all people have attitudes that result in tendencies to respond positively or negatively to another person, a group of people, an object, a message, a situation involving objects and people, or an idea.

The study reviewed and evaluated above was an attempt to establish the attitudinal responses of a large group of workers about specific details of a preventive medicine and safety program operation for the control and elimination of laboratory-acquired infections. Over-all, the responses show a generally favorable attitude

[1]J. A. Malfetti, "Attitudes and Safety in Recreation," Public Health Reports, 78, (1963) p. 477.

toward the program and the specific engineering, enforcement, and educative features that are a part of it. There was no evidence of the existence of large-scale hostile or negative attitudes toward safety.

Partitioning of the responses provided a basis for comparing group attitudes by pointing to sizable differences in the response of 540 laboratory personnel compared with that of 391 craft workers. The purpose of the comparison was to detect in the laboratory group tendencies to respond to accident prevention techniques, regulations, or situations, the improvement of which might be of benefit to the safety endeavor or reveal hitherto uncovered accident causal factors. Comparison of the laboratory group with the craft workers provided a relative basis for judging the degree of agreement between group responses to questions. The relative degree of the infectious hazard presented to the laboratory personnel, it must be remembered, is of a much higher order of magnitude than that of the craft workers. The latter, as a group, would be roughly comparable to a working group in an industrial firm, whereas the laboratory group would be roughly comparable to a research group at a college or university.

In examining the responses of the two groups, the response differences of the greatest probable significance were:

1) Fort Detrick laboratory workers, as a group, were less sure than the craft workers that their supervisors were always conscientious in reporting all accidents.

2) As compared with the craft group, laboratory workers did not have as high a regard for the value of safety rules and regulations. Moreover, laboratory people were not as sure as craft workers that adherence to regulations would improve safety without sacrificing work efficiency.

3) Laboratory workers did not believe as strongly as craft workers that better reporting would result in improvements by uncovering causes of laboratory infections.

4) Laboratory workers did not feel as strongly as craft workers about the importance of accidents that seem insignificant at the time they occur in later producing occupational infections.

5) Among the laboratory group there was some tendency to feel that an imbalance existed in the quality and quantity of the safety equipment provided, whereas craft workers were reasonably satisfied with the quality but tended to feel that more equipment was needed.

6) Laboratory workers apparently tended to have less faith than craft workers in the effectiveness of safety councils, conferences, and lectures in reducing accident risks in their own work areas.

7) The group response of laboratory people was not as good as that of the craft people in indicating a willingness to obey the regulation requiring that all illnesses be reported immediately to the Fort Detrick physician. The fact that 14 per cent of the laboratory group indicated that they would report "only if symptoms persist" signals what may be a significant medical and safety problem.

8) A greater proportion of the laboratory workers than craft workers agreed with the statement that Fort Detrick is a safe place to work. The poor response of the craft workers on this question, although they indicated general satisfaction with the working conditions and safety program, is difficult to explain. One

possible reason would be a desire on the part of craft workers not to endanger the hazard pay granted to hourly employees. Certainly, the response of the craft workers was somewhat conservative. On the other hand, the response by the laboratory group reflects a less conservative attitude because, although a majority felt that Fort Detrick was a safe place to work, one-fourth felt that taking deliberate risks was occasionally justified.

There can be little doubt that the group attitudes of the laboratory workers, as compared with those of the craft workers, were substantially different on a number of important points relating to safety. Laboratory workers appeared not as willing to accept value statements without definite proof, thereby tending to be conservative in subjective evaluations and bold in stating opinions that may conflict with well-known policy or regulation. The laboratory group's answers, to a greater extent than those of the craft group, reflected a searching for the meaning of the questions before answering. Although the answers by the craft group may indicate a greater degree of conformity with existing safety precepts, "knowing the right answer to put down" may not have an important relation to attitude operation in an accident situation. Even so, there is indication that craft workers may have received more and better safety training and orientation than the laboratory workers. This, indeed, is underscored by the fact that laboratory workers more often work at individual projects and are less accustomed to participation in work group activities than craft workers. Independent workmanship is more typical of a laboratory person than of the craft person, who usually is a member of a crew, with a crew foreman, shop steward, supervisor, etc. It is probably important to note differences in training techniques that may be required for such diverse groups, as well as the relative appeal to the individual of such devices as posters or safety slogans.

C. COMPARATIVE STUDIES WITH ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

1. Testing Conditions and Validity and Reliability of the Test Instruments

The case studies involved six trial, 11 control, and 66 test subjects. The control case studies included five accident-involved persons and six accident-free individuals. The 66 test subjects included 33 accident-involved persons and a similar number who had been accident-free for at least two years.

The six trial interviews were conducted to give the investigator experience in introducing and guiding the interview and in arranging the questions in the most profitable order. Test conditions that appeared most desirable were selected and time estimates were obtained for later use in scheduling. Questions or discussion topics most likely to arouse resentment were identified and reframed to elicit the most cooperative response. After his interview each subject was told its purpose and asked to help by making suggestions.

As a result of the trial interviews the following conditions and procedures were established:

1) A maximum of two hours was allowed for each interview. This avoided the overlapping of schedules and the necessity for subjects to wait to be interviewed.

2) Telephone calls and other disruptions were eliminated during the interviews.

3) Coffee was offered to each subject and smoking was allowed.

4) Room conditions and contents were standardized. Paper and pencils as well as a blackboard were available in the interview room to assist subjects in explaining details of accidents, etc.

5) Preliminary comments and explanations to be made to each subject were standardized.

The interviews and tests were given individually in a small conference room. Usually most of the allotted two hours was required for each subject. No control was exercised over the selection of the accident-involved subjects except that accidents involving more than one person were not considered and several accident reports describing events that were questionable for classification as accidents were discarded.

Particular attention was paid to the selection of the accident-free subjects. Each subject met most or all of the following criteria for matching with his accident-involved counterpart:

1) Worked in the same laboratory building, in the same branch or section.

2) Performed the same types of laboratory tasks.

3) Had the same job classification and approximately the same pay rate.

4) Was of the same sex. (In only one instance was it impossible to obtain an accident-free subject of the same sex.)

The validity of the test instruments depended in part on subjective evaluations by the committee of experts who individually reviewed and commented on the interview outline. Minor changes and additional questions were added by this review process. The committee was unanimous in its opinion that the interview schedule, as applied to accident-involved and accident-free subjects, would serve as a valid instrument in revealing factors relating to accident cause, particularly with regard to human factors. None of the committee responded to a request to suggest other test instruments or procedures that might be more suitable.

In the control interviews with the five accident-involved subjects, validity was further established from the finding that in each case accident information not contained in the initial accident report was uncovered. Thus there was assurance that in the test group the instrument would serve its intended purpose, that of uncovering additional facts bearing on accident cause.

The reliability of the test instruments and procedures was established by the test-retest method. Each of the 11 control subjects (five accident-involved persons and six accident-free persons) was given the interview two times with an interval of one week between.

Reliability measures for the interview were also established on a subjective basis. All of the subjects gave the same personal and background information on both interviews. With several subjects the second interview resulted in recall of some additional details about accidents but none was considered to add a significant amount of information.

Moreover, reliability was measured by observing the frequency with which the subject's answers for the initial questions differed from those he recorded on the retest one week later. Each of the 11 control subjects, upon retest, answered differently from 7 to 14 of 49 questions. However, examination of the individual responses showed that in only about one question per person did the differences reflect a definite change of response. Most differences were minor, as for example the difference between excellent and good or the difference between poor and unsatisfactory.

Also, by predicting perfect duplication on the retest and by using the number of retest questions that were actually answered in the same manner, calculation of a chi square value of 17.4 at df = 10 failed to provide sufficient evidence to reject the hypothesis of equal test results at the 0.05 level of significance.

2. Similarities Between the Groups

The general hypothesis used in comparing data from the two test groups was that no difference between the groups existed with reference to the item in question. The items discussed below are those for which, by simple inspection or by application of statistical test, insufficient evidence to reject the null hypothesis was collected. It is important to note that the matching or pairing of individuals for the accident-involved and accident-free groups was based on job classification, type of work, sex, building location, and estimated level of hazard of work performed. No other bias was knowingly included; physical characteristics such as age, weight, height, and personal factors such as marital status, physical condition, schooling, etc., were unknown to the investigator until after each interview.

Because of the method of selecting matched individuals, the job classifications, pay categories, and sex of the two groups were equivalent, as shown in Table 107.

TABLE 107. CHARACTERISTICS OF THE ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Job Classification	Number of Accident-Involved People	Number of Accident-Free People
Trained scientific personnel	5	5
Laboratory technical assistants	22	22
Animal caretakers	6	6
Pay category		
GS 9 - 11	5	5
GS 3 - 7	14	14
WB 4 - 11	14	14
Sex		
Male	32	31
Female	1	2

Characteristics of the two groups that were not influenced by selection are shown in Table 108. No differences in mean age, weight, height, length of employment, or amount of formal education were detected. Because there was no difference between the mean length of employment of the two groups, each group had had the opportunity to accumulate approximately the same amount of sick and annual leave. Table 108 shows that the average amount of sick and annual leave accumulated by members of the two groups was not significantly different. Therefore, it may be presumed that the average use-rate of annual and sick leave for the two groups was the same. Present Civil Service regulations allow an accrual of 30 days of back annual leave. It is interesting that members of both groups tended to accumulate the maximum amount. Moreover, three members of each group qualified for membership in the so-called 1000-hour sick leave club.

TABLE 108. COMPARISON OF ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Question Item	33 Accident-Involved People		33 Accident-Free People		"t" value at df = 64
	Mean Value	Standard Deviation	Mean Value	Standard Deviation	
Age	38.0 years	8.8	38.0 years	8.1	-
Weight	169 pounds	21.8	171 pounds	25.2	0.345[a]
Height	68.6 inches	3.1	68.6 inches	2.8	-
Length of employment	10.9 years	4.3	10.8 years	4.7	0.091[a]
Formal schooling	11.6 years	2.5	11.4 years	3.5	0.270[a]
Accumulated sick leave	56.7 days	40.2	63.3 days	42.0	0.653[a]
Accumulated annual leave	32.6 days	13.7	27.7 days	15.5	1.357[a]

a. At 0.05 level of significance the hypothesis of equal means is accepted.

Analysis failed to reveal differences in the physical condition of the subjects as judged from their use of prosthetic or corrective devices, from their statements as to the presence of constitutional disease or other symptoms and ailments, or from their statements as to the use of insulin, benzedrine, tranquilizers, and other drugs. Seventeen members of the accident-involved group and 16 members of the accident-free group wore eye glasses.

Table 109 summarizes the statements of the subjects regarding length of time since their last illness requiring a doctor's care and their last physical examination.

TABLE 109. TIME SINCE LAST PHYSICAL EXAMINATION AND LAST ILLNESS REQUIRING A DOCTOR'S CARE

Question Item	Accident-Involved Group	Accident-Free Group
Time since last physical examination		
Number of subjects	33	33
Mean time, years	2.32	3.64
Standard error of difference between means	1.42	
"t"	0.930	
Time since last illness requiring a doctor's care		
Number of subjects	33	33
Mean time, years	1.27	1.18
Standard error of difference between means	0.50	
"t"	0.180[a]	

a. At df = 64 and at the 0.05 level of significance the hypothesis of equal means is accepted.

For both responses, the average time in years was not different between groups. In addition, the illnesses described by the two groups were not judged to be different; almost all were stated to be colds, flu, or sore throat.

With respect to living arrangements, the members of the two groups did not differ, as shown in Table 110.

TABLE 110. LIVING ARRANGEMENTS FOR THE ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Question Item	Accident-Involved Group	Accident-Free Group
Owned home	9	7
Buying home	11	13
Renting	13	13
Chi square	0.879[a]	

a. At df = 2 and at the 0.05 level of significance, the hypothesis of equal frequencies is accepted.

Each respondent was asked about his hobbies and recreational activities. Hunting and fishing were the most popular activities in both groups. About 40 per cent of each group stated that they hunted or fished. To provide a method of comparison, the activities listed were classified as (i) those done primarily out of doors and away from home and (ii) those done indoors or at home.* There were a total of 96 responses from the accident-involved group and 93 from the accident-free group. Chi square analysis of the responses failed to detect significant differences between the recreational activities of the two groups (Table 111).

TABLE 111. HOBBIES OF ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Question Item	Accident-Involved Group, %	Accident-Free Group, %
Outdoor sports and activities	54	47
Indoor or at-home activities	46	53
Chi square	1.693[a]	

a. At df = 1 and at the 0.05 level of significance the hypothesis of equal frequencies is accepted.

No differences between the groups were detected with regard to their off-the-job accident records and their driving records. Six individuals (18 per cent) in each group had had serious, off-the-job, non-motor-vehicle accidents. (These were mostly falls resulting in broken limbs.) As shown in Table 112, there were also no significant differences between the numbers of people who had had motor vehicle accidents and moving traffic violations. There was little difference in the total number of accidents and violations for the two groups. The seriousness of the accidents and violations was not different for the members of the two groups. When points were assigned to the violations according to Maryland traffic laws, the total points for each group were approximately the same. One individual in each group had been the driver of an automobile involved in a fatal traffic accident.

Evaluations failed to reveal significant or important differences in the responses of the two groups to a number of "opinion" questions about safety. These results are summarized below. The numbers represent the positive responses from the accident-involved and the accident-free groups respectively:

	Accident-Involved Group	Accident-Free Group
Safety is a worthwhile endeavor.	33	33
It is not desirable to eliminate all hazards from our daily lives.	18	21

*For example, hunting, fishing, golf, and boating are typically outdoor sports done away from home. Raising flowers, breeding dogs, collecting stamps, and cooking are activities typically done at or in the home.

	Accident-Involved Group	Accident-Free Group
The emphasis on safety at Fort Detrick is about right.	28	27
The Safety Division staff is effective in improving safety.	30	30
Safety Division personnel do a good job of handling safety problems.	27	25
Safety Division personnel are fair and just in their dealings with employees.	31	31
The safety regulations are good.	31	26[a]
My supervision in safety is satisfactory.	25	25
Positive feeling toward increased social and recreational affairs for Fort Detrick employees.	24	24
Fort Detrick is a safe place to work.	30	32
The amount of safety equipment available is about right.	31	31
The quality of the safety equipment is as good as or better than necessary.	26	27[a]
The frequency of disinfection procedures is about right.	26	21[a]
Elimination of some safety rules would not affect the safety of my job.	28	29
One should not take deliberate short cuts and risks.	29	31
Positive attitude toward the value of following safety regulations.	31	30
I would report a careless co-worker to the Safety Officer.	17	13[a]
Almost all accidents in my laboratory are reported.	25	29
Seemingly unimportant accidents may result in laboratory infections.	29	30
Positive attitude toward reporting accidents.	33	33
Detection of accident causes would be significantly improved by better reporting.	20	23[a]
If I did not feel well, I would report immediately to the Fort Detrick doctor.	30	29
The immunization shots give me good protection.	28	27
Supervisory personnel at Fort Detrick set a good safety example.	30	30
My supervisor always encourages me to report minor accidents.	27	29
The laboratory Safety Council is effective.	18	23[a]
The Post Safety Council is effective.	20	22[a]
Safety lectures and conferences improve work safety.	33	28
If I were starting all over, I would work at Fort Detrick again.	33	30
I intent to continue to work at Fort Detrick until retirement.	31	31

a. Indicates that the chi square analysis of the total question response failed to show differences between groups at the 0.05 level of significance.

TABLE 112. TRAFFIC ACCIDENTS AND VIOLATIONS BY ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Question Item	Accident-Involved Group	Accident-Free Group
People who had traffic accidents	12	11
(Total number of accidents)	(19)	(15)
People who had no traffic accidents	21	22
Chi square	0.034[a]	
People who had moving violations	12	14
(Total number of violations)	(20)	(18)
People who had no moving violations	21	19
Chi square	0.279[a]	

a. At df = 1 and at the 0.05 level of significance the hypothesis of equal frequencies is accepted.

Each subject was asked to discuss what immediate steps could be taken in his laboratory to improve safety. Then he was asked to discuss what additional things he would do if he possessed unlimited funds and authority. The responses to these questions by the two groups were substantially the same (Table 113).

After his interview, each subject was asked how he felt about the interview and was invited to contribute any additional thoughts relative to personal factors in accident prevention. All of the subjects stated that they considered the interview to be the probable best way to uncover personal factors. Most subjects stated that they preferred note-taking by the investigator rather than recording the interview. On the whole, the cooperation of the subjects was excellent. Two of the accident-involved individuals initially seemed reluctant to discuss the details of their accidents, but eventually were able to relax and give adequate details. A third accident-involved subject appeared to be a disgruntled and dissatisfied employee; he did not seem to fit into his job and made repeated statements concerning his desire to change jobs or serve under another supervisor. There appeared to be considerable personal hostility between this individual and his supervisor. The remaining 63 subjects were cooperative and at the conclusion stated that they were not offended by the questions and discussion. The investigator found, in fact, that with a few individuals it was difficult to limit the interview time to the scheduled two hours and occasional adjustments had to be made in the interview appointment schedule.

3. Differences Between the Groups

The fact that subjects in the two groups possessed different characteristics or reacted differently to interview questions does not, in itself, identify accident

TABLE 113. SAFETY SUGGESTIONS BY ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Steps That Could Be Taken to Improve Safety in Your Laboratory	Accident-Involved Group	Accident-Free Group
No changes recommended	11	10
Changes in equipment and facilities	14	14
Changes in training, selecting, supervision, and assignment of personnel	8	9
Chi square	0.211[a]	
With unlimited funds and authority:		
No changes recommended	7	10
Changes in equipment and facilities	14	11
Changes in training, selecting, supervision, and assignment of personnel	12	12
Chi square	1.718[a]	

a. At df = 2 and at the 0.05 level of significance the hypothesis of equal frequencies is accepted.

causes. However, such differences are suggestive of the types of human factors that are associated with accident-involved persons to a greater extent than with accident-free persons. Naturally, these factors will vary in their significance and subjective evaluations of their importance become increasingly necessary. The ways in which the two groups of subjects were different are treated below.

Although no group differences were detected in the health status, the use of drugs, etc., the studies did reveal significant differences in smoking and drinking habits (Table 114). All persons who stated that they drank alcoholic beverages further stated that they drank in moderation. Most smokers used cigarettes at the rate of one pack per day.

Thus the accident-free group was composed of a significantly greater number of individuals who stated that they neither smoked nor drank alcoholic beverages. In the accident-involved group three persons stated that they were opposed to anyone's smoking and two persons were opposed to anyone's drinking alcohol. In the accident-free group four persons were opposed to both smoking and drinking.

Although none of the respondents indicated that his relatives or family disapproved of his working at Fort Detrick, the two groups reacted somewhat differently to a question about job approval:

Question Item	Accident-Involved Group	Accident-Free Group
Wives, family, or relatives approve of my working at Fort Detrick	23	30
It doesn't matter to them	10	3

TABLE 114. SMOKING AND DRINKING HABITS OF THE ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Question Item	Accident-Involved Group	Accident-Free Group
Do you smoke?		
Yes	29	19
No	4	14
Chi square	11.196[a]	
Do you drink alcoholic beverages?		
Yes	27	23
No	6	10
Chi square	4.288[a]	

a. At df = 1 and at the 0.05 level of significance, the hypothesis of equal frequencies is rejected.

A possible explanation for this result is that the accident-free group included more individuals to whom it would be important to have family approval of their occupation and place of employment. This, in turn, may indicate closer family ties for the accident-free group. Such a possibility is further illustrated by a comparison of the marital status of the two groups as shown in Table 115.

There were four divorced individuals in the accident-involved group but none in the accident-free group. About the same number of people in each group were married and had children, but the mean number of children per parent was significantly higher in the accident-free group; 3.36 compared with 2.38. On the average, each married, accident-free individual who had children had one child more than the married parent in the accident-involved group.

The previous on-the-job accident records of the accident-involved people differed markedly from those of the accident-free individuals. This was expected because the latter were selected on the basis of a two-year accident-free record. However, when the accident records of the two groups prior to the current two years were compared there was still a marked difference (Table 116).

TABLE 115. MARITAL STATUS OF ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Question Item	Number of Accident-Involved People	Number of Accident-Free People
Married	27	29
Married, with children	24	25
Single	2	4
Divorced	4	0
Mean number of children per parent	2.38	3.36
Standard deviation	1.06	1.68
Standard error of the difference between means	0.40	
"t"	2.450[a]	

a. At df = 47 and at the 0.05 level of significance the hypothesis of equal means is rejected.

TABLE 116. PREVIOUS ACCIDENT RECORDS OF ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Previous Accident	Accident-Involved Group	Accident-Free Group
Laboratory Injuries		
No	28	33
Yes	5	0
Laboratory Infections		
No	21	30
Yes	12	3
Chi Square	29.700[a]	

a. At df = 1 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

Table 116 shows that a dichotomy in accident experience had existed within the two groups for a period even longer than the two years. Since there were no significant differences in job classification and length of service, the differences cannot be due to different amounts of laboratory exposure. The dichotomy is further illustrated by comparison of the non-lost-time accidents reported by the individuals in the two groups. Table 117 lists these accidents according to type of injury. The accident-involved group had had almost twice as many minor accidents as the accident-free group.

TABLE 117. PREVIOUS NON-LOST-TIME ACCIDENTS REPORTED BY ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Accident Type	Number of Accidents	
	Accident-Involved Group	Accident-Free Group
Lacerations	40	24
Contusions	13	9
Biological exposures	11	1
Strains and sprains	8	3
Eye injuries	7	5
Burns, hot liquids or steam	6	4
UV burns	4	2
Animal bites	4	4
Chemical splashes	3	1
Exposures to toxic fumes	2	1
Totals	105	61

Compared with the accident-involved group, the accident-free individuals were more critical or more conservative in rating their supervisors. Five questions about supervisors were asked. In each the employee was asked to estimate how frequently his supervisor was fair to all persons, assumed his responsibilities, kept his promises, kept employees informed, and gave credit where credit was due. The combined answers to these five questions showed that the accident-involved people more frequently gave higher ratings for their supervisors than did the accident-free people (Table 118).

TABLE 118. RATINGS OF SUPERVISORS BY ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Does Your Supervisor Fulfill His Obligations?	Ratings	
	Accident-Involved Groups	Accident-Free Groups
Always	91	63
Usually	64	81
Sometimes	6	13
Seldom	4	8
Chi square	21.781[a]	

a. At df = 3 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

Because in almost all cases the paired individuals were rating the same supervisor, it is obvious that the accident-free individuals were the more critical in their evaluation.

In regard to opinions about the safety consciousness of co-workers, the evaluations by the accident-free group also were more conservative than those by the accident-involved group (Table 119).

Thus the accident-free group did not assume that the safety consciousness of their co-workers was as high as that assumed by the accident-involved group. Obviously, this trend could have an important relationship to the ability of a person to

TABLE 119. RATING OF CO-WORKERS BY ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Do You Feel Your Co-workers Are Safety Conscious on Their Jobs?	Accident-Involved Group	Accident-Free Group
Always	14	7
Usually	17	21
Sometimes or rarely	2	5
Chi square	9.562[a]	

a. At df = 2 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

remain accident-free. In the same way that a good motor vehicle driver is a defensive driver and does not assume that other drivers will always drive safely, a defensive attitude on the part of a laboratory worker, in which he does not assume that his co-workers will always perform safely, will function to prevent his involvement in accident situations.

The accident-free subjects were also more conservative in their rating of working conditions on the job (Table 120).

TABLE 120. EVALUATION OF WORKING CONDITIONS BY ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Rated Working Conditions	Accident-Involved Group	Accident-Free Group
Excellent or very good	23	16
Satisfactory	10	17
Chi square	5.126[a]	

a. At df = 1 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

Although none of the respondents graded conditions as unsatisfactory, it is evident that the accident-free people were more reluctant than accident-involved people to rate conditions as excellent or very good.

Compared with the accident-involved group, the accident-free group also placed greater importance on proper attitudes toward safety (Table 121).

TABLE 121. OPINIONS ON ATTITUDES AND EQUIPMENT BY ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Question Item	Accident-Involved Group	Accident-Free Group
Which is the more important?		
Proper attitude toward safe procedures	20	27
Techniques, equipment, and inspections	13	6
Chi square	8.607[a]	

a. At df = 1 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

Respondents in each group were asked to rank a number of techniques according to how they stimulated positive feelings toward accident prevention. The combined results are shown in Table 122.

TABLE 122. RANKING OF SAFETY PROGRAM TECHNIQUES BY ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS

Safety Program Technique	Ranks	
	Accident-Involved Group	Accident-Free Group
Safety meetings	1	1
Personal experience from previous accidents	2	6
Formal training programs	3	2
Safety bulletins	4	3
Safety inspections	5	4
Published regulations	6	7
Safety posters	7	5

Ranked order correlation coefficient, $r^1 = 0.57$, "t" = 1.568.

Although these two sets of ranks yielded a positive correlation coefficient, the value was not sufficiently large to allow rejection of the hypothesis that $P = 0$. In examining the ranks, it is interesting to note the relative value to individuals in the two groups of personal experience from previous accidents. The accident-involved group graded this as the second most important factor in stimulating their thinking about safety. The present and past accident experience of this group, however, belies the value of this factor in preventing accidents among its members. Members of the accident-free group, on the other hand, gave personal experience a low rating relative to the other factors listed. Both groups agreed that safety meetings had the greatest stimulating effect on their thinking about safety and both groups ranked published safety regulations and safety posters relatively low.

In another question, respondents were asked if having an accident would make them more or less likely to have another of the same type. Although 32 of 33 persons in each group stated that they would be less likely to have a similar accident, it appears that the confidence that accident-involved people placed in the preventive value of previous accident experience was excessive. Persons who have remained relatively free of accidents, conversely, appear to attach but little preventive value to the experience gained from their accidents.

During the interviews, each respondent was asked, "What irritates you most about the safety program?" Approximately 50 per cent of each group could think of no irritating factors. The nature of the answers is summarized in Table 123.

TABLE 123. RESPONSE OF ACCIDENT-INVOLVED AND ACCIDENT-FREE GROUPS ABOUT SAFETY PROGRAM IRRITATIONS

What Irritates You Most About the Safety Program?	Accident-Involved Group	Accident-Free Group
Nothing	16	18
Inadequate or inconsistent enforcement of safety regulations	6	10
Improper use or condition of equipment or facilities	1	4
Taking immunizations	0	1
Safety is over-emphasized and delays and restricts operations	7	0
Safety personnel are not aware of the problems	2	0
Going to safety meetings	1	0
Totals	33	33

Individuals in both groups stated that they were irritated by inadequate or inconsistent enforcement of the safety regulations. However, seven of the accident-involved group, but none of the accident-free group, stated that safety was over-emphasized and delayed or restricted their work to the point that they felt irritated. Thus, in spite of other questions about the amount of emphasis that should be placed on safety, it appears that the accident-involved group, to a greater extent than the control group, contained individuals who were somewhat hostile toward the safety program.

4. Causes of Accidents Sustained by Accident-Involved Group

The interview outline contained 24 questions that provided the basis for collection of detailed information about the accidents occurring to the accident-involved subjects. The questions were designed to encourage discussion of certain personal factors and opinions that might have a bearing on accident causation.

Each accident-involved subject was asked to discuss what he felt caused his accident. The primary cause was listed and then each subject was questioned regarding other possible causes. Statements of principal cause were evaluated and grouped into the categories shown in Table 124.

TABLE 124. CAUSES OF ACCIDENTS BY ACCIDENT-INVOLVED GROUP

Principal Cause	Number of Subjects	Per Cent
Unsafe act or personal failure	20	60.6
Equipment failure	5	15.2
Combined equipment and personal failure	7	21.2
Unknown (laboratory infection)	1	3.0

Each subject was also asked if he could foresee that the accident in question was going to happen and if a different reaction on his part would have prevented the accident or reduced its severity. The answers were:

	Yes	No
Did you foresee that the accident was going to happen?	2	31
Would a different reaction on your part have prevented the accident or reduced its severity?	11	22

In spite of the answers to the second question, further discussion and evaluation revealed that in 17 additional cases different reactions on the part of the subjects would probably have prevented the accident or reduced its severity. Only five of the 33 accidents (those due to equipment failure) were judged by the investigator as not being preventable by last-minute different reactions by the subjects. Obviously constant awareness and accident perception ability play an important role in a person's ability to avoid accidents. It appears that the accident-involved subjects often lacked the ability to perceive accident situations in time to prevent the accidents.

This point is further illustrated by the reactions to the question "What did you do to try to avoid the accident when you realized it was going to happen?" Only four subjects stated that they made some move or motion to avoid the accident. Two subjects stated that even though they realized the hazard, in the face of the impending accident, they continued to follow the SOP* because "this is what I am supposed to do." The 27 remaining subjects stated that they did not or could not take any last-minute avoidance measures. As stated above, the investigator's evaluation was that 28 of the subjects could have taken last-minute measures that would have prevented the accident or lessened its severity.

In addition to the problem of lack of accident perception, the two individuals who continued to follow the SOP illustrate that inflexibility of technique and working habits in the face of an impending accident may sometimes be a problem.

Some examples of accidents that could have been prevented by different reactions are given below:

*Standard Operating Procedures.

1) Failed to hold animal securely for inoculation. Continued attempt to inoculate the animal even though animal was moving and struggling.

2) Failed to get help to lift heavy equipment. Even though he could not lift the equipment on the first try, he continued the attempt.

3) Failed to wear gloves to pick up broken glassware. Gloves were readily available.

4) Placed a contaminated syringe in a hazardous location. He noticed its hazardous location several times but failed to move it.

5) Failed to move a long extension cord to a safe place. Tripped on the cord several times before the accident occurred.

6) Used a glove for the wrong purpose.

7) Removed safety glasses.

Discussions with the 33 accident-involved subjects also revealed that being in a hurry or working at an abnormal rate of speed was a contributing factor in a significant proportion of the accidents. In twelve of the 33 accidents (36 per cent) the subjects admitted that they were working at an abnormal speed. A frequent reason given for being in a hurry was that the subject wanted to finish the task before lunch time or before the end of the work day.

Other contributing factors were present less frequently. Four individuals stated that distractions, such as noise or the movement of other individuals in the room, contributed to their accidents. Two persons felt that poor illumination was a contributing factor and one individual stated that a high room temperature contributed to his accident.

Review of the 33 accidents revealed a recognized violation of existing safety regulations in 10 instances (30 per cent). Moreover, the responses to the question "To your knowledge, was there a violation of a safety regulation involved?" showed good correlation with the investigator's evaluation. The accident-involved people answered this question as follows:

No	23
Yes	8
Undecided	2

None of the individuals who violated regulations felt that the regulations were unreasonable or needed revision. This comparison provides a basis for rejecting the hypothesis that the accident-involved people tended to be unfamiliar with the safety regulations.

Each subject was asked to describe exactly what he did immediately following his accident and asked if he felt that he should have acted differently. Each subject's answer was subjectively evaluated in light of all known facts and a determination was made as to the adequacy of the action. On this basis, 24 of the 33 subjects (73 per cent) acted in the best possible manner following their accidents:

Excellent:	(Action correct in all respects)	24
Good:	(Action essentially correct but not all necessary action taken or not in the proper order)	3
Fair:	(Person eventually took necessary actions but allowed other things to come first)	2
Poor:	(Only part of the necessary action taken)	3

Discussions with the 33 individuals failed to reveal that their activities on the night before or on the day of the accident were significantly different from their usual activities. All individuals claimed to have had an adequate amount of undisturbed sleep. Almost all were at home the evening before and only two could remember drinking alcoholic beverages. On the day of the accident only one of the 33 individuals was doing work that was different to any degree from his usual activities except that, as previously stated, 12 individuals were working at an abnormal speed.

An essential part of the studies with accident-involved individuals was a comparison of the information collected from each person with the information resulting from the normal reporting and investigative efforts. The records were in general agreement with the interview results with regard to the frequency of accidents due solely to personal failures. However, only rarely did either method attach any degree of personal failure to the supervisors of the accident-involved people. In other words, on the accident reports and during the interviews there was a reluctance to mention any supervisory failure that might have contributed to the accidents. Also, the accident records showed that equipment failure was the sole cause of nine accidents, whereas the interviews showed that equipment failure actually was the sole cause in only five of the nine accidents.

The interviews invariably produced more details and a greater insight into the causal factors related to each accident than did the accident records. For example, the fact that 12 subjects felt that working at an abnormal speed was in part the cause of their accidents or that four others described certain physical distractions as contributing factors was not reflected in the accident records. In addition, the lack of accident-perception ability as a causal factor was not reflected in the records.

As shown in Table 125, a number of types of accidents were sustained by the 33 individuals.

Six of the accidents resulted in loss of work time; four were laboratory infections. Fifteen of the accidents were classified as biological, 15 as industrial, and three as combined biological and industrial.

The tasks being performed at the time of the accidents, in order of significance, were:

Performing routine diluting and plating operations.

Washing, handling, or sterilizing glassware.

Performing aerobiological experiments.

Exposing, injecting, or autopsying animals.

Handling bulk quantities of infectious materials.

TABLE 125. ACCIDENTS SUSTAINED BY ACCIDENT-INVOLVED GROUP

Accident Type	Number	Per Cent
Lacerations and contusions	9	27.3
Spills or exposures to infectious materials	7	21.2
Laboratory infections	4	12.1
Burns	4	12.1
Accidental self-inoculation with syringe and needle	4	12.1
Animal bites	3	9.1
Chemical exposures	2	6.1
Totals	33	100.0

On the basis of a review of the statements made by the accident-involved people it appears that an important and predominant causal factor was the inability or failure of some individuals to realize that a hazardous situation was building up to a point where an accident was probable. Alternatively, the failure in some cases may not have been the inability to recognize so much as it was the inability or failure to take appropriate action at the time of recognition. This, of course, could be termed "excessive risk taking," but it also is appropriately related to a lack of accident-perception ability. At least one discovered cause for failure to act following the perception of an accident situation was the excessive work speed being maintained by 30 per cent of the individuals. Moreover, a characteristic inclination to "take the risk" is illustrated by the fact that eight individuals were aware that a safety regulation was being violated and two others were undecided as to whether or not a violation was involved. The importance of this is strengthened by the fact that none of these ten individuals felt that the regulations involved were unreasonable.

Thus it can be concluded that a lack of accident-perception ability, the reluctance or inability to take precautionary measures in the face of a recognized accident situation, and a willingness to take a chance by violating a safety regulation were important cause factors characteristic of the accident-involved group.

5. Comments by Accident-Free Subjects

A part of the interview time with each accident-free person was devoted to discussions to discover what factors or items each individual felt had been important in preventing his involvement in accidents and what personal philosophy or code if any each associated with his freedom from accidents.

Thirty-two of the 33 individuals felt that an accident-free work record was "something to be proud of." One individual responded negatively, apparently because he felt such a record to be a job responsibility.

In ranking items that had personal significance toward the prevention of accidents, the accident-free group rated safety equipment such as ventilated cabinets as the most important item. Next, of personal importance, was the training and guidelines the individuals received from their supervisors, followed by personal protective equipment, safety training and orientation lectures, and the safety regulations. Each person was asked to consider whether any of a list of items had been of value to him personally. The most frequently mentioned item was safety support from top management.

In an attempt to gather other data on how these individuals had maintained an accident-free record, each person was asked to imagine that he had been chosen for promotion and that he had been asked to instruct and train his replacement on how to work safely in the job he was leaving. To obtain the best response, role-playing techniques were employed for this question, with the investigator playing the part of the person to be trained. This question elucidated considerable discussion. Digests of the comments of the 33 individuals are presented below.

<u>Subject</u> <u>Digest of Responses</u>

1. Be on the ball by following the safety regulations. The first violation of a regulation should be followed by a warning. The next time you should be be given time off without pay.

2. Make people aware of the hazard of being exposed. Follow the safety regulations and be aware of the hazards.

3. Have no fear, but do have respect for the infectious agent you work with. Be aware of the hazards.

4. Develop self-discipline in observing the safety regulations. Use common sense. Slow down and live.

5. Follow the SOP's as closely as possible. Plan enough time to do the job.

6. Be careful and follow the safety regulations.

7. Follow your supervisor's instructions and the SOP's for the job. Workers should assist each other in being aware of the hazards and in following the SOP's.

8. Have common sense and awareness of the hazards involved. Be fully informed with the safety literature and aware of the hazards. Have respect for all infectious agents.

9. Follow the safety regulations. Think. Be safety-conscious at all times and be aware of the hazards. Strictly follow the SOP's.

10. Be safety-conscious and be aware always of the hazards. Develop your awareness and follow the regulations.

11. Obey the safety rules and regulations. Be aware of the hazards and respect the infectious agents.

12. Respect all biological agents and follow all safety regulations. If there is a violation you should be warned the first time and removed from the job the second time.

13. Be cautious and aware of the hazards.

14. Have awareness of the hazards and respect for all agents. Insist on good safety management for your own welfare and for the welfare of your fellow workers.

15. Always be aware of hazards and have respect for all agents. Emphasize cautiousness.

16. Be safety-conscious and have respect for all agents. Develop good attitudes.

17. Benefit from previous accident experiences. Become safety-conscious and have high respect for the agents. Stick to the regulations and consider all work as hazardous.

18. Have great respect for the agents. Try to become safety-conscious.

19. Be safety-conscious and respect the hazards of the job.

20. Have no fear. Learn all you can about safety. Have respect for the hazard of all agents. Remember that all agents are dangerous.

21. Learn and obey the safety rules and regulations. Be safety-conscious and respect all agents.

22. Have the proper attitude towards safety. Plan each job properly and respect all agents. Learn all you can about safety.

23. Think before you act. Respect all agents and be safety-conscious.

24. Read the safety regulations and follow them.

25. Remember past accident experiences and be safety-conscious. Then follow all safety regulations and respect all agents.

26. Become efficient in the required techniques and obey the SOP's and safety regulations.

27. Think before you act. Follow all SOP's and have respect for the hazard of all agents.

28. Fear of being hurt should make you constantly careful. Use the proper equipment, don't take chances, and remember the potential hazards.

29. Work carefully and take the necessary precautions. If you have a feeling that something is wrong, stop and check.

30. Think about your family and your kids and this will cause you to work carefully at all times. Safety is a part of the job. A supervisor must act safe himself in order to teach others to be safe. Ask questions, read, and discuss the laboratory problems. Don't be afraid to say "I don't know."

31. Think things through before you act. Plan the work first—lay it all out—and then proceed with caution after checking with the supervisor and with the regulations.

32. Remember that no accidents are "minor." Before starting a job, try to understand the background of the work and why it is being done. Be sure of what you are going to do before you do it. Remember that the regulations are for your own good and that it is poor technique that can get you into trouble.

33. Plan your work, take your time and use good judgment. When you make changes, you must be careful not to introduce new hazards.

The most important observation that derives from study of the responses of the 33 accident-free individuals is their innate awareness of human factors involvement in accidents. In the role-playing carried out by these laboratory people there was little emphasis or even mention of physical or mechanical things in accident prevention. For example, no mention was made of the checking of glassware before it is used, the use of proper personnel protective devices, checking for adequate ventilation of ventilated safety cabinets, the use of safety containers or boxes, the use of pipettor, needle-locking syringes, etc. Instead, these individuals spoke primarily about matters relating to the person himself, his required personal actions, his feelings and his desired attitudes. It appeared that almost every subject assumed that the proper equipment and physical barriers would be present and that it was the human element that required emphasis in the instruction of a person who was to take over his job.

In the terms used by the role-players, the most frequent specific comments concerned the need to have <u>respect</u> for the infectious agents, <u>respect</u> for the hazards, or an <u>awareness</u> of the hazards. These specific comments appeared 26 times during the 33 interviews. In reality the subjects were attempting to describe how they felt their replacements should feel and respond to the laboratory work situation and how these feelings should be reflected in behavior in order to maintain an accident-free record. They were therefore referring to attitudes and to human factors involvement. Two persons pointedly mentioned the need for the development of the proper attitude.

It appears significant that the words "aware" and "respect" were used so frequently during the role-playing sessions. Some individuals were able to amplify their statements by specific details related to awareness and respect. Awareness of hazards meant (i) knowing what techniques or operations presented hazards, (ii) not forgetting these as time goes on, and (iii) letting this awareness be the guide for the way in which one carried out laboratory techniques and procedures. Respect for the infectious agents or for the hazards was in most cases a recommendation not to "live in fear" but rather to attempt to display confidence in laboratory work by purposeful planning and approaches in recommended and safe techniques.

Eighteen of the 33 individuals stressed the need to follow the safety regulations or SOP's. Even those who did not mention the regulations specifically assumed that they were to be followed.

A summary of the role-playing comments by the 33 accident-free individuals is shown in Table 126. It is concluded from these data that those factors considered most important for an accident-free existence by the 33 individuals were predominantly those related to attitudes toward safety and the control of human factors involvement in accidents.

TABLE 126. SUMMARY OF COMMENTS BY 33 ACCIDENT-FREE INDIVIDUALS DURING ROLE-PLAYING

Nature of Comments	Number of Individuals
Follow safety regulations and SOP's	18
Have respect for infectious agents and hazards	16
Be aware of the hazards	10
Be safety conscious	7
Think and use common sense	6
Plan the job carefully	5
Be cautious	4
Follow supervisor's instructions	3
Rely on previous accident experience	2
Have no fear of biological agents	2
Have fear of biological agents	2
Develop good attitudes	2
Use proper equipment	1
Develop efficient techniques	1
Insist on good safety management	1

Several additional interview questions for accident-free persons were similar to other questions previously summarized. However, these questions were different in context because they concerned a person's feelings about himself. Although most subjects gave published safety regulations a low rating for ability to stimulate positive feelings toward accident prevention, it is obvious that the accident-free individuals, nonetheless, felt that attention to these regulations was by far the most important code to follow in order to remain accident-free.

Moreover, it was clear that most individuals did not consider possible punitive action that might result from not following the regulations, but tended, rather, to think of the types of hazards to be avoided by following the rules. This reaction on the part of the accident-free subjects can be best expressed as respect for safety regulations and an understanding of the hazards the regulations attempt to control.

It is interesting, also, to contrast this attitude with that recounted previously, in which 30 per cent of the accident-involved people knowingly violated a regulation and thereby caused an accident. From this it is reasonable to conclude that the accident-involved persons, as a group, had less respect and confidence in the regulations than did the accident-free group.

D. CONCLUSIONS

Eighty-three individuals were used in the case studies. Six were studied as preliminary trial subjects, 11 were included in the control studies in which the test-retest method was employed, and 66 made up the actual test group. The latter group was composed of 33 accident-involved and 33 accident-free persons.

The conclusions drawn from these group studies were:

1) Selection of matched individuals for inclusion in the two test groups was satisfactory with respect to type of laboratory, job classification, pay category, and sex.

2) The data collected failed to provide sufficient evidence to establish significant group differences with regard to:

a) Age, weight, and height of the members of the two groups.

b) Amount of formal schooling.

c) Length of employment and amount of accumulated sick and annual leave.

d) General physical condition and length of time since last physical examination or illness requiring a doctor's care.

e) Frequency of use of drugs.

f) The wearing of eye glasses.

g) Living arrangements with respect to owning, buying, or renting homes.

h) Favored hobbies and means of recreation.

i) Off-the-job accident and driving records and moving traffic violations.

3) The two groups responded in like fashion to 31 "opinion" questions. The questions ranged from those about the general worth of any safety effort to specific questions about the hazards of laboratory work, questions on safety procedures that should be followed, and questions about the usefulness of various committees and devices used in the safety program. It is possible that the responses elicited by these questions reflected an effort on the part of members of both groups to give the correct answers.

4) Discussion with members of the two groups did not reveal differences in the steps the subjects felt could be taken to improve safety in their individual laboratories.

5) The accident-free group differed from the accident-involved group in the following respects:

a) More non-smokers and non-drinkers were in the accident-free group.

b) More members of the accident-involved group had been divorced.

c) Among the married persons, the accident-free fathers, on the average, had more children than the fathers in the accident-involved group.

d) There was evidence to suggest that the accident-free individuals had closer family ties than the accident-involved individuals.

e) For the employment period prior to the current two years, the accident-involved group had had far more laboratory infections, lost-time injuries, and non-lost-time accidents than the accident-free group, thus indicating that a more or less permanent dichotomy had existed between the safety performances of the two groups.

f) The accident-free group was more conservative or critical in evaluating the safety efficiency of their supervisors and co-workers or in rating the adequacy of working conditions, thus providing evidence that the accident-free workers tended to have "defensive" work habits in regard to laboratory hazards.

g) More individuals in the accident-free group realized the importance of proper attitudes in safety endeavors.

h) The accident-involved group appeared to place excessive reliance on experience gained from accidents in avoiding later accidents.

i) The accident-involved group contained more individuals who had some hostile feelings toward the safety program.

6) The lack of accident-perception ability was revealed as a significant cause factor among accident-involved persons.

7) Unsafe acts or personal failures were responsible for the accidents sustained by 82 per cent of the accident-involved subjects.

8) Inflexibility of work habits, that tends to preclude last-minute modification when an accident situation is recognized, seems to play a part in the causation of some laboratory accidents.

9) Working at an abnormal rate of speed in order to finish a laboratory task within a specified time interval was a significant causal factor.

10) Physical factors such as noise, illumination, or room temperature were contributing causal factors in 18 per cent of the accidents.

11) Although members of the accident-involved group were aware of the safety regulations and did not believe them to be unreasonable, intentional violations of these regulations were a significant cause of their accidents. This is termed excessive risk taking.

12) Once an accident occurred, the action taken by most accident-involved people was satisfactory.

13) The performance of routine laboratory procedures such as diluting and plating cultures was the most frequent task being performed at the time of the accidents.

14) In contrast to those accident-involved individuals who took excessive risks by violating a known safety regulation, the accident-free group placed prime importance on understanding and following the safety regulations. Therefore, it is apparent that the meaningfulness of the regulations was less for some of the accident-involved people compared with 31 of the 33 accident-free persons.

15) In role-playing exercises, accident-free persons revealed that the most important type of training or instruction that they would give to people to help them remain accident-free would be instruction regarding the human element in accident prevention. Although expressed in various ways, the accident-free individuals seemed to possess an innate understanding of the importance of human factors.

VIII. REPORTED CAUSES OF LABORATORY ACCIDENTS

The final result of the investigation of an accident should be the assignment of the principal cause or causes and recommendations to prevent recurrence of that type of accident. Assignment of cause, in a practical sense, should result from a consideration of the accident factors: the accident type, the agency, unsafe acts, unsafe conditions, and unsafe personal factors. Recommended corrective actions for individual accidents are based on the assigned causes but must reflect a knowledge of what action is practical and profitable and is likely to be accomplished under existing management directives, policies, etc.

Data in this chapter deal with reported causes entered on accident records; they represent decisions and actions taken by supervisors and safety officers during the functioning of a day-to-day safety program. Analyses of these decisions are included in this study because they provide an opportunity for comparison, on a group basis, with significant causes uncovered in preceding chapters. In general, the causes referred to in this chapter constitute an attempt to locate, without specifying exact details, the person, persons or equipment whose faulty performance contributed to the accident. In addition, the data on stated causes provided a basis for testing the hypothesis that most of the unknown causes of laboratory infections arise not from faulty equipment but from unnoticed or undetected human error in the manipulation of infectious cultures. This chapter was also selected as the proper place to review and summarize some commonly recognized laboratory accidents that frequently lead to infection.

A. REPORTED ACCIDENT CAUSES

The reported primary causes of the Fort Detrick laboratory accidents are summarized in Table 127.

TABLE 127. REPORTED CAUSES OF 1218 LABORATORY ACCIDENTS

Stated Cause	Number of Accidents	Per Cent
Employee at fault	564(14)[a]	46.3
Equipment at fault	239 (8)	19.6
Combined human and equipment failure	112 (2)	9.2
Supervisor at fault	62	5.1
Another work group at fault	50	4.1
Unknown	191(23)	15.7
Totals	1218(47)	100.0

a. Parentheses denote lost-time accidents.

A typical problem with microbiological accidents is again illustrated by these data, because approximately one-half of the lost-time accidents (all were infections) and approximately 15 per cent of all accidents were classified as being of unknown cause.

For the above data, human failure was known to have occurred in at least 65 per cent of all accidents, equipment failure caused approximately 20 per cent of the accidents, and the remaining 15 per cent are in the questionable unknown category. The following analyses attempt to develop further useful information in relation to these cause categories.

Probably, the reported data are deficient in regard to supervisory failure. The Fort Detrick policies clearly establish the principle of a supervisor's responsibility for the safety of his employees. In fact, this responsibility usually constitutes a part of a supervisor's written official job description. It is understandable that there is a natural reluctance on the part of accident-involved people to indicate that the supervisors failed to discharge their responsibility in preventing accidents. Therefore, little significance should be placed on the frequency with which supervisory failure was listed on the accident records other than the fact that a human failure was recognized.

Table 128 shows the assigned causes according to the type of laboratory accident. All of the lost-time accidents for which no causes were found were biological accidents resulting in infection. With biological accidents, this table also identifies the seriousness of accidents caused by equipment failure; one in 13 accidents of this type resulted in infection.

TABLE 128. CAUSES OF INDUSTRIAL, BIOLOGICAL, AND COMBINED ACCIDENTS

Cause	Industrial	Biological	Combined
Employee at fault	262(6)[a]	207 (6)	96(2)
Equipment at fault	110(1)	89 (7)	40
Combined human and equipment failure	51(2)	41	20
Supervisor at fault	29	23	10
Another work group at fault	23	19	8
Unknown	88	69(23)	33
Totals	563(9)	448(36)	207(2)

a. Parentheses denote lost-time accidents.

Those accidents involving infectious materials for which the mode could be identified are shown in Table 129. Again, the importance of inhalation exposures is emphasized because these made up only 46 per cent of the accidents but accounted for almost 80 per cent of the infections. The role of equipment failure is also emphasized because, for inhalation accidents, one in every eight exposures resulted in infection. Moreover, these data show that all but one of the infections of unknown cause were acquired by inhalation of infectious microbial aerosols.

TABLE 129. ACCIDENT CAUSES CLASSIFIED ACCORDING TO MODE OF INFECTION OR EXPOSURE

Cause	Inhalation	Direct Inoculation	Skin Contamination	Ingestion
Employee at fault	134(3)[a]	106(3)	51(1)	3(1)
Equipment at fault	58(7)	46	22	0
Combined human and equipment failure	27	21	10	0
Supervisor at fault	15	12	6	0
Another work group at fault	12	10	4	0
Unknown	46(21)	36(1)	18	0
Totals	292(31)	231(4)	111(1)	3(1)

a. Parentheses denote lost-time accidents.

That the laboratory infections were markedly different from the lost-time injuries in reported causes is shown in Table 130.

TABLE 130. COMPARISON OF CAUSES OF LOST-TIME INJURIES AND INFECTIONS

Cause Category	Number of Infections	Number of Lost-Time Injuries
Human failure	5	11
Equipment failure	7	1
Cause "Unknown"	23	0
Totals	35	12

Thus it is clear that the problem with unknown causes exists in the case of the infections, whereas causes were determined for all of the lost-time laboratory injuries. On the other hand, if the people involved in only non-lost-time injuries and non-infection-producing biological accidents are considered, there appear to be no differences in the general causal categories, as shown in Table 131.

TABLE 131. COMPARISON OF CAUSES OF NON-LOST-TIME BIOLOGICAL ACCIDENTS AND INJURIES

Cause Category	Non-Lost-Time Biological Accidents		Non-Lost-Time Injuries	
	Number of Involved Persons	Per Cent	Number of Involved Persons	Per Cent
Human failure	705	54.9	425	53.1
Equipment failure	410	31.9	257	32.1
Cause "Unknown"	169	13.2	119	14.8
Totals	1284	100.0	801	100.0

These data, which include all persons involved in non-lost-time accidents, show human failure and equipment failure to be the primary cause of about the same proportions of the biological accidents as the non-lost-time injuries. Moreover, the proportion of unknowns in each group suggests that the efficiency of the accident investigations was about the same for the two types of accidents.

The listed causes of the non-biological accidents classified according to the nature of the injuries sustained by the involved people are shown in Table 132.

These data show that:

1) A laceration where the person injured was at fault is the single most frequent cause-injury combination, followed by a laceration wherein the equipment was judged to be at fault.

2) Employee at fault was the most important cause of lost-time injuries; nine of 11 injuries were in these categories.

3) Although equipment [illegible] for each type of injury, [illegible] were even [illegible] feelings that were [illegible] equipment failure therefore [illegible] personal failure.

4) The [illegible] number of these injury [illegible]

TABLE 132. CAUSES OF INDUSTRIAL LABORATORY ACCIDENTS ACCORDING TO THE NATURE OF THE INJURIES

Stated Cause	Number of People Receiving				
	Lacerations	Contusions	Eye Injuries	Burns	Strains and Sprains
Employee at fault	153(3)[a]	31	27	18(3)	17(3)
Equipment at fault	148	30	26	18	16
Combined human and equipment failure	43	9(1)	8	5(1)	4
Supervisor at fault	33	7	6	4	3
Another work group at fault	23	5	4	3	2
Unknown	67	13	11	8	10
Total injured people	467(3)	95(1)	82	56(4)	52(3)

a. Parentheses denote lost-time accidents.

Further consideration of the data in Table 132 failed to show that the type of injuries received was influenced by the causes of the laboratory accidents. That is, no evidence was found that would reject an hypothesis of unequal weights in the various rows (the causes) as influenced by the columns (the injuries). This is illustrated in Table 133, where those data of Table 132 are expressed as percentages.

Thus, insofar as total injury-producing accidents are concerned, there appear to be no detectable trends in causal factors as a function of the type of injury received.

The specific problem of unknown causes for the lost-time accidents is further illustrated bv the analysis shown in Table 134.

Expected numbers of lost-time accidents in three cause categories were established from the relative number of non-lost-time accidents. The frequency of equipment failure as a cause of lost-time accidents was closely predicted from the frequency of minor accidents. However, humans were observed to be at fault only about one-half as frequently as expected, and 16 more accidents than expected were in the no-cause-uncovered category. Classification of these 16 accidents as being due to human failure would obviously equate the expected and observed frequencies. The hypothesis so formed is that most of the unknown causes were primarily human failure as opposed to equipment failure. The required assumption for this hypothesis is that all accidents must have a cause.

TABLE 133. CAUSES OF INDUSTRIAL LABORATORY ACCIDENTS ACCORDING TO PER CENT OF PEOPLE RECEIVING VARIOUS INJURIES

Stated Cause	Per Cent of People Receiving				
	Lacerations	Contusions	Eye Injuries	Burns	Strains and Sprains
Employee at fault	32.8	32.6	32.9	32.1	32.7
Equipment at fault	31.7	31.6	31.7	32.2	30.8
Combined human and equipment failure	9.2	9.4	9.8	8.9	7.7
Supervisor at fault	7.1	7.4	7.3	7.7	5.8
Another work group at fault	4.9	5.3	4.9	5.4	3.8
Unknown	14.3	13.7	13.4	14.3	19.2

TABLE 134. OBSERVED AND EXPECTED CAUSES OF LOST-TIME LABORATORY ACCIDENTS

Cause	Number of Lost-Time Accidents		
	Expected	Observed	Chi Square
Humans at fault	31	16	
Equipment at fault	9	8	
No cause uncovered	7	23	43.940[a]

a. At df = 2 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

Direct unequivocal proof of the above hypothesis was not obtained from this research. However, by process of elimination there can be little doubt that human error produced most of those accidents classified as of unknown cause. The comparisons shown in Tables 135 and 136, for example, provide support for the hypothesis.

In Tables 135 and 136, specific categories of unsafe acts and unsafe conditions are classified according to the stated causes. Note that 67 per cent of all accidents and 83 per cent of lost-time accidents with no listed causes were those for which no unsafe condition was found (Table 135). Conversely, 59 per cent of all accidents and 91 per cent of the lost-time accidents for which no cause was uncovered were listed under unknown unsafe acts (Table 136).

TABLE 135. UNSAFE CONDITIONS IN RELATION TO THE CAUSES OF LABORATORY ACCIDENTS

Unsafe Condition	Cause		
	Humans at Fault	Equipment at Fault	No Cause Uncovered
Defective condition of equipment or apparatus	87(1)[a]	167(6)	13
Hazardous process, operation, or arrangement	64(8)	14(1)	30(4)
Unsafe dress or apparel	82(3)	7	2
Unsafe design or construction of equipment or apparatus	46(2)	18	-
Inadequate guarding	50	3	1
Use of wrong type of equipment or apparatus	30	-	1
Inadequate or incorrect ventilation or air filtration	17	7(1)	2
Leaking or nontight equipment	8	7	1
Inadequate or incorrect illumination	8	-	1
Inadequate or incorrect decontamination equipment	4	1	-
Miscellaneous	83(1)	7	12
None	309(1)	8	128(19)
Totals	788(16)	239(8)	191(27)

a. Parentheses denote lost-time accidents.

That not all the 191 unknown-cause accidents should be considered as exclusively due to human failure is illustrated by the fact that in 63 instances some type of unsafe condition was identified, even though the investigators labelled the accident as of unknown cause (Table 135). But, in Table 136, 26 of the no-cause accidents were related to known and identified unsafe acts.

Additional conclusions concerning primary causes that are derived from Tables 135 and 136 are:

1) Although about 40 per cent of accidents due to equipment failure also were identified with unsafe acts, most of the more serious accidents (those producing

TABLE 136. UNSAFE ACTS IN RELATION TO THE CAUSES OF LABORATORY ACCIDENTS

Unsafe Act	Cause		
	Humans at Fault	Equipment at Fault	No Cause Uncovered
Handling equipment in an unsafe manner	321(3)[a]	1	8(1)
Use of unsafe or improper equipment	117(1)	49(1)	1
Failure to wear proper protective devices	86(5)	-	6
Operating at unsafe speeds	60(1)	4	2
Removing, altering, or not using safety equipment	29(3)	2	1
Performing operations prohibited by regulations	26(2)	1	1
Dropping cultures, tools, etc.	17	2	-
Failure to follow instructions	18	-	-
Failure to report unsafe conditions	15	3	-
Miscellaneous	52	7	7
Unknown	16(1)	25(1)	112(21)
None	31	145(6)	53(1)
Totals	788(16)	239(8)	191(23)

a. Parentheses denote lost-time accidents.

lost time) occurred in the absence of recognized unsafe acts. Moreover, equipment failures were more often due to a defective condition than to poor design, inadequate guarding, or improper use. From 12 to 14 per cent of the laboratory accidents were due primarily to equipment failure without concurrent and recognized unsafe acts. Because equipment included glassware, which is subject to breakage during use, the need for two types of corrective measures derive from this causal factor: (i) the need for substituting nonbreakable plastic ware for glassware whenever possible, and (ii) the need for rigid inspection of glass apparatus before its use. Because equipment also refers to items such as mixers, blowers, grinders, air filters, cabinets, etc., the need for proper periodic inspection and maintenance is illustrated. However, it is predicted that elimination of these causes would reduce the number of non-lost-time and lost-time accidents by no more than 14 per cent.

2) Theoretically, the remaining 86 per cent of the laboratory accidents are those in which human failure led to unsafe acts that directly or indirectly precipitated accidents. However, there is considerable evidence that performance of such acts exists at at least two levels of detection; in other words, a dichotomy of types of unsafe acts. One consists of actions easily recognized by laboratory personnel, accepted as undesirable by most workers, and conveniently recorded in appropriate categories. The other category, much more elusive in nature and more related to infections than injuries, probably exists primarily at the work surface used by the workers and pertains to their individual movements and techniques, regardless of whether or not they or others accept these techniques or movements as unsafe. The second category, in other words, may involve the micro-climate in the immediate vicinity of the worker's face that unknowingly may be inoculated with disease-producing microbes from unrecognized slips in technique. Assignment of possible preventive measures for each recognized unsafe act follows logically. Most preventive measures would fall within the accident-prevention techniques of education and enforcement. A method of preventing unsafe acts that defy recognition, however, is more difficult. Externalization of the worker from his micro-climate work area through the use of protective cabinets is probably the best prevention measure.

3) Among recognized types of unsafe acts that caused laboratory accidents, several are identified as presenting a higher than average risk of lost time. A general estimate of these risk levels is shown in Table 137.

TABLE 137. ESTIMATE OF RISK OF LOST TIME DUE TO UNSAFE ACTS

Unsafe Acts Causing Accidents	Ratio of Lost Time to Total Accidents
Removing, altering, or not using safety equipment	1:10
Performing operations prohibited by regulation	1:13
Failure to wear proper protective devices	1:17
Operating at unsafe speeds	1:60
Handling equipment in an unsafe manner	1:107
Use of unsafe or improper equipment	1:117

4) The most hazardous unsafe condition causing lost-time accidents was setting up a laboratory process or arrangement that, by its very nature, presented an inherently hazardous condition. One in every eight of these accidents resulted in lost time. There is obviously no safe alternative to proper arrangement or positioning of instruments and equipment used in carrying out laboratory research. Failure to see that equipment and apparatus used is safely designed and constructed also creates conditions leading to lost-time accidents.

B. RECOGNIZED CAUSES OF LABORATORY INFECTIONS

Certain categories of accidents resulting in infections occurred regularly in all of the data examined by the investigator. The five most frequent of these are considered below. They are (i) bites and scratches when handling animals, (ii) accidental inoculation with syringe and needle, (iii) oral aspiration of infectious or toxic fluids, (iv) sprays of infectious or toxic fluids from syringes, and (v) accidental breakage of tubes of culture during centrifuging. Information on their relative frequency from eight data sources is shown in Table 138.

TABLE 138. FREQUENT CAUSES OF LABORATORY INFECTIONS AND ACCIDENTS

Data and Source	Per Cent of Accidents or Infections Due To				
	Animal Bites	Syringe Inoculation	Oral Aspiration	Spray from Syringe	Centrifuge Accidents
1342 Infections Sulkin and Pike (U.S., 1930-1950)	2.4	4.3	2.5	a/	0.5
718 Accidents (NIH, 1954-1956)	1.7	2.2	4.0	0.6	0
602 Accidents (CDC, 1959-1962)	5.8	3.0	1.8	0.8	0.5
921 Infections (literature survey)	a/	2.7	17.7 b/	a/	a/
2459 Minor Accidents (Fort Detrick, 1954-1961)	6.6	4.9	9.3	0.7	0.0
426 Infections (personal visits)	0.7	4.7	0.5	1.2	1.2
385 Infections (Fort Detrick, 1944-1962)	0.3 c/	2.6	1.0	1.3	0.0
641 Infections Pike, Sulkin, and Schulze (world-wide, 1950-1963)	2.2	5.6	1.6	a/	0

a. Data not available.
b. Includes splashes of cultures, etc. into mouth.
c. Bite from infected tick.

Regardless of whether infections, all accidents, or only minor accidents are considered, the combined percentages of the five procedures accounted for no more than

20 per cent of the total, and usually considerably less. Data of this type are the basis for the statement that the causes of approximately three-quarters of laboratory infections are unknown because no faulty technique or accident was known to have occurred.

Oral aspiration of infectious cultures by pipettes when manipulating cultures of infectious microorganisms continues to be an important cause of laboratory infection, although it was one of the first microbiological laboratory hazards to be recognized. The earliest publication dealing with the prevention of laboratory infections appeared in the same year (1915) as the first survey of collected cases. Paneth,[1] in that year, pointed out that the common method of pipetting infectious cultures with mouth and finger offers two types of hazards. First, the inadvertent aspiration of infectious materials into the mouth and, second, the contamination of the mouthpiece with one's own finger, which then results in oral contamination. Paneth collected information on the causes of 47 laboratory infections, mostly typhoid fever. He found that 17, or 36 per cent, were due to oral pipetting. Moreover, he concluded that use of a rubber bulb for pipetting would avoid both types of hazards and that using a rubber hose attached to the pipette would avoid the first hazard and reduce the probability of the second.

In 1950 Wedum[2] described a number of devices for nonautomatic pipetting in the microbiological laboratory. In the same year Schafer,[3] in Germany, pointed out that mouth pipetting should be outlawed and made the following comments:

> Of course that is basically the way things are when it comes to infections with typhus strains. Pipetting with live cultures must in the technique of bacteriological-serological typhus diagnosis be regarded as in practice the chief source of laboratory infections. This is the more difficult to understand in that here in contrast to many unnoticeable possibilities of infection (unpacking incoming material, etc.) we are dealing with a readily understood work process. The best-intentioned preventive prophylaxis (protective vaccination) does not achieve its end if it is not complemented by an equally conscientious exposure prophylaxis. Pipetting, to be sure, is unavoidable, but safety precautions can—and, the balance of our survey compels us to say, must—be taken that are capable of reducing the danger of infections.

The irony of the situation with regard to pipetting hazards is that, although they are widely recognized and easily prevented, only limited progress has been made toward their elimination. Most persons who handle infectious cultures continue to put pipettes into their mouths. Several large institutions such as Fort Detrick and the Naval Biological Laboratories have outlawed mouth pipetting. Also, in West Germany, a federal regulation prohibits mouth pipetting of dangerous substances. Nevertheless, in this country during a recent three-year period the following types of mouth-pipetting accidents were reported at one microbiological research laboratory:

[1]L. Paneth, "The Prevention of Laboratory Infections," Medizinische Klinik, 11 (1915), pp. 1398-1399.

[2]A. G. Wedum, "Nonautomatic Pipetting Devices for the Microbiologic Laboratory," Journal of Laboratory and Clinical Medicine, 35 (1950), pp. 648-651.

[3]W. Schafer, "Laboratory Infections Especially with Typhoid Bacilli," Archiv fur Hyg u Bakteriol, 132 (1950), pp. 15-32.

Types of Fluids Sucked into Mouth	Number of Accidents
Acids and alkalies	17
Infectious cultures	8
Toxic solvents	2
Poisons	1
Radioactive materials	1

Bloom[1] has shown that with radioactive solutions, in addition to the danger of aspiration of fluid, there is a hazard due to the inspiration of vapors. Using a syringe to simulate mouth action, Bloom showed that traces of tritium oxide were detectable in the air aspirated from unplugged pipettes. He recommended control of these hazards by "...the simple issuance of a decree forbidding the oral pipetting of radioactive materials." When the author repeated Bloom's experiments, using bacterial cultures instead of tritium oxide, it was shown that mouth pipetting can result in oral contamination by aerosol particulates drawn up through unplugged pipettes.

It is common misconception that plugging the mouthpieces of pipettes with non-absorbent cotton provides adequate protection during mouth pipetting. However, overzealous mouth aspiration sometimes sucks the cotton into the mouth along with a quantity of fluid. Even plugged pipettes do not avoid the oral contamination transferred from the fingers via the pipette mouthpiece. It is obvious that prevention of pipetting accidents should begin with an edict from each laboratory director outlawing mouth pipetting.

Animal bites sustained by laboratory workers are usually due to the failure to wear proper protective equipment, a lack of the proper skill in handling laboratory animals, or both. As with pipetting accidents, animal bites are largely preventable.

People are usually exposed to sprays from syringes when a needle accidentally separates from the syringe barrel. This type of accident is largely prevented by the use of syringes with locking tips to secure the needle. Likewise, centrifuge accidents are largely prevented by use of safety trunnion cups or by enclosure of the centrifuge in a ventilated cabinet.

Accidental infections with Brucella abortus, strain 19, among veterinarians and veterinary students during the past 10 years illustrate the problem of syringe and pipette safety. Because of its low virulence, this strain, in addition to its use for vaccinating cattle, is widely used in teaching laboratories, classroom demonstrations, and in numerous research projects. Yet, even with its low virulence, there have been a number of accidental infections among students, veterinarians, and other research workers. Fifteen cases published in the literature (10 from the U.S. and Canada and 3 from England) were recently summarized by Revich, Walker, and Pivnick.[2] One case was due to mouth pipetting a culture and the others resulted either from syringe and needle inoculation accidents or from sprays of culture into the face and eyes when a needle separated from a syringe during use. Undoubtedly there have been many other infections among students and others that have not been reported.

[1] B. Bloom, "The Hazard of Orally Pipetting Tritium Oxide," Journal of Laboratory and Clinical Medicine, 55 (1960), p. 164.

[2] S. J. Revich, A. W. Walker, and H. Pivnick, "Human Infection by Brucella abortus Strain 19," Canadian Journal of Public Health, 52 (1961), pp. 285-289.

The accidental inoculation with syringe and needle is the most difficult of the five accident types to prevent. It often occurs as a result of an involuntary reflex reaction when a needle sticks or slips or when an animal being injected moves suddenly. Persons holding animals for injection are sometime injected by the person holding the syringe. One approach to the prevention of syringe inoculation accidents is the elimination of the use of syringes and needles wherever possible. For operations requiring a needle and syringe the use of a one-hand syringe manipulator[1] improves safety by permitting easier manipulation and by leaving one hand free to steady the animal being injected.

C. CONCLUSIONS

Routine analysis of the causes of Fort Detrick laboratory accidents during a four-year period, examined retrospectively, identified human error in at least 65 per cent of the accidents and equipment failure as the primary cause of 20 per cent. The causes of approximately 15 per cent of all accidents were not found. This latter group contained 49 per cent of all the lost-time accidents and 60 per cent of the occupational infections. Further data were developed in support of the conclusion that the unknown causes were primarily human errors occurring in the immediate vicinity of laboratory workers and consisting of unsafe acts that are particularly difficult to recognize and detect because there is no instantaneous means of recognizing the escape of infectious microbial aerosol. Enclosure of infectious operations in ventilated cabinets and appropriate educational and enforcement activities appear to be the best preventive means.

Failure of laboratory equipment during infectious operations was an important cause of occupational infection.

Human error was the most frequent cause of all types of injuries sustained in the laboratory. There was no evidence to show that the cause factors differed substantially among different types of laboratory injuries.

The three most hazardous unsafe acts resulting in lost-time accidents were (i) removing, altering, or not using safety equipment, (ii) performing operations prohibited by regulation, and (iii) failure to wear proper protective devices.

Among almost 8000 biological accidents and infections, the five most frequently recognized accident types were animal bites, syringe inoculations, oral aspirations, sprays from syringes, and centrifuge accidents. Together, these accounted for no more than 20 per cent of the laboratory infections. Most have been recognized since the early days of microbiology and can be readily prevented. Unfortunately, safe practices and equipment to eliminate these accidents have not been widely accepted.

[1] A. B. Weathersby, "One-Hand Manipulator for Hypodermic Syringes," American Journal of Clinical Pathology, 36 (1961), p. 94.

IX. CORRECTIVE ACTIONS FOLLOWING LABORATORY ACCIDENTS

Consideration of the corrective actions taken following laboratory accidents forms an appropriate part of this study because the single purpose of causal information is for use in prevention. However, because the analysis below constitutes a frank examination of a practical, operating safety effort carried on without much of the information developed in previous chapters, it is to be expected that the actions taken will not always be supported by causal information. Specifically, it is to be noted that the corrective actions tabulated from the accident records are not always synonymous with preventive actions. In the laboratory, decontamination following a biological accident may well be required as a corrective action but it has no value in preventing recurrence of the same type of accident that created the contamination.

A break-down of the corrective actions taken following the Fort Detrick accidents is shown in Table 139. Of specific importance in these data is the fact that no corrective action was taken following 18 per cent of the accidents. This is explained in part by the previous finding that approximately 16 per cent of the 1218 accidents were of unknown cause. However, if only lost-time accidents are considered, we find that although 23 were of unknown cause, only 13 of these were not followed by corrective action. In other words, corrective measures were employed following 10 of 23 accidents, even though little was known of their cause.

TABLE 139. CORRECTIVE ACTIONS TAKEN FOLLOWING LABORATORY ACCIDENTS AT FORT DETRICK

Corrective Action	Number of Accidents	Per Cent
Employee warned, advised, cautioned	432 (2)[a]	35.5
Equipment replaced or repaired	158 (6)	13.0
Procedures changed, modified, or eliminated	139 (9)	11.4
New safety equipment ordered or designed	79 (9)	6.5
Area decontaminated or sterilized	68 (1)	5.6
Employee retrained or re-instructed	49 (4)	4.0
Inspection or testing procedures instituted	49 (3)	4.0
Warning devices or guards installed	24	2.0
None	220(13)	18.0
Totals	1218(47)	100.0

a. Parentheses denote lost-time accidents.

As shown in Table 139, warning, advising, or cautioning employees was by far the most frequently used corrective action for non-lost-time accidents, whereas changing, modifying, or eliminating certain procedures or providing new safety equipment were the corrective measures most frequently taken following lost-time accidents.

Table 140 shows the corrective actions in relation to the class of accident.

TABLE 140. CORRECTIVE ACTIONS FOLLOWING INDUSTRIAL, BIOLOGICAL, AND COMBINED ACCIDENTS

Corrective Action	Accident Class		
	Industrial	Biological	Combined
Employee warned, advised, cautioned	196	163(2)	73
Equipment replaced or repaired	73(2)[a]	58(2)	27(2)
Procedures changed, modified, or eliminated	64(3)	51(6)	24
New safety equipment ordered or designed	36(2)	29(7)	14
Area decontaminated or sterilized	31	25(1)	12
Employee retrained or re-instructed	23(1)	18(3)	8
Inspection or testing procedures initiated	23(1)	18(2)	8
Warning devices or guards installed	11	9	4
None	101	81(13)	38
Totals	558(9)	452(36)	208(2)

a. Parentheses denote lost-time accidents.

Here it is evident that, although all three classes of accidents are represented in the no-corrective-action column, only in the biological accidents were lost-time accidents represented. Moreover, because of the low ratios of total to lost-time accidents, the efficiency of changing and eliminating procedures and providing additional safety equipment is suspected.

Table 141 shows the corrective actions taken compared with the reported causes of the accidents.

It becomes obvious that these data cannot be logically or satisfactorily explained unless each accident is considered separately. However, these data show what corrective actions were employed for the unknown-cause accidents. It becomes obvious also that human failure was not always corrected by action toward humans.

Thus the action following 245 of 788 human-failure accidents (31 per cent) does not appear to be one that would directly prevent repetition of the human error except to the extent that engineering changes made the faulty action impossible or inconvenient. On the other hand, in these grouped data, it appears inconsistent that in 83 instances equipment failure was followed by warning, advising, or cautioning employees.

TABLE 141. CORRECTIVE ACTIONS COMPARED WITH REPORTED CAUSES OF ACCIDENTS

Corrective Actions	Primary Cause		
	Human Failure	Equipment Failure	Unknown
Employee warned, advised, cautioned	280(2)[a]	83	69
Equipment replaced or repaired	103 (3)	31(2)	24 (1)
Procedures changed, modified, or eliminated	89 (5)	28	22 (4)
New safety equipment ordered or designed	51 (2)	16(5)	12 (2)
Area decontaminated or sterilized	44	13	11 (1)
Employee retrained or re-instructed	32 (4)	10	7
Inspection or testing procedures initiated	32	10(1)	7 (2)
Warning devices or guards installed	15	5	4
None	142	43	35(13)
Totals	788(16)	239(8)	191(23)

a. Parentheses denote lost-time accidents.

In Table 142, similar categories of corrective actions have been combined to allow analysis of the action following lost-time accidents. The proportion of non-lost-time accidents in each corrective action category was used as a basis for establishing expected frequencies. The chi square analysis allows rejection of the hypothesis that the two distributions are equivalent. The greatest difference in the two distributions is between the expected and the observed frequency with which action directly involving the employee was taken.

At this point reference may be made to previous data in which it was shown that human failure was classified as the cause of lost-time accidents only about one-half as frequently as predicted. By this process of reasoning one detects a possible unbalance in the nature of the corrective actions as related to the causal factors. Thus, if 80 per cent or more of the laboratory accidents are due to human failure, this proportion of the corrective activities should be directed toward the humans.

TABLE 142. OBSERVED AND EXPECTED CORRECTIVE ACTIONS FOLLOWING LOST-TIME LABORATORY ACCIDENTS

Corrective Action	Number of Lost-Time Accidents		
	Expected	Observed	Chi Square
Employee warned, retrained, etc.	19	6	
Equipment repaired, replaced, modified, etc.	10	15	
Procedures changed, tested, eliminated, etc.	10	13	
None	8	13	15.420[a]

a. At df = 3 and at the 0.05 level of significance the hypothesis of equal frequencies is rejected.

X. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The principal aim of this research, conducted by consideration of four related subproblems, was to identify causal factors that are responsible for producing accidents and occupational infections in microbiological laboratories. The over-all research method used can be best called the epidemiological approach because the interrelations and interactions of hosts, accident agencies, and environments were examined in relation to accident causation.

Three almost unique problems confronted the investigator at the outset of this research. The first was the accepted and reasonable requirement of universality. That is, the problem being investigated should be shown to be of sufficient magnitude at a national or international level to warrant a concentrated research effort. Also, universality meant that there should be sufficient evidence that the results obtained or the conclusions reached would find application to groups of workers other than those at Fort Detrick. In other words, because the study was to be concerned in large part with the Fort Detrick laboratory population, it was necessary to show that the safety problems encountered by this work force were not substantially different from those of other infectious disease researchers and that a common ground could be established for the solution of the problems.

The second problem concerned the unusual combinations of incapacitating or injury-producing agents to which microbiological laboratory employees may be exposed. In addition to the usual types of accident agencies such as floors, stairs, tools, etc., these laboratory employees may be infected by pathogenic microorganisms, injured or diseased by chemical substances, and injured and/or infected by laboratory animals. Thus it was required that an unusual number of possible accident-producing agencies be considered in the epidemiological approach.

The third problem was that no previous over-all compilation or summaries of existing information on the causes of microbiological laboratory accidents and infections had been made since the recognition of the problem late in the 19th century. Hundreds of publications describing laboratory infections and several dozen surveys of infections published since 1897 contained only a limited amount of causal data. Except for several statistical studies by the Bureau of Labor Statistics, no data were available on the causes of injuries in microbiological laboratories. Studies of the probable hazards of a variety of laboratory procedures had been published, but adequate proof of the causal relationships was lacking. Therefore, as a part of this research it was necessary to provide a precise characterization of the microbiological laboratory safety problem. One chapter in this report is concerned with this characterization. It allowed a greater understanding of the problems and provided much causally related data.

A. SUMMARY AND CONCLUSIONS

The major findings resulting from this research are summarized below.

1) Since the first recorded laboratory infections in 1885, the problem of accidental occupational disease among laboratory workers has expanded as the discipline of microbiology has grown. Even today, the causes of most infections are listed as unknown.

2) The accidental infection problem is not confined to one or several institutions, but is ubiquitous wherever infectious disease microorganisms are used. In this respect the problem is universal.

3) Laboratory infections normally occur at a frequency of as many as five infections per million man-hours worked. Occasionally, however, epidemics occur during which large segments of a laboratory population, including students, become occupationally infected. A general estimate of the combined mechanical, chemical, and biological frequency rate for microbiological laboratories is 6.25 per million man-hours.

4) The expected case fatality rate for laboratory infections is approximately 4.0 compared with 2.7 for motor vehicle accidents. Because some infectious diseases tend toward chronicity and may produce personality or other changes, severity rates for nonfatal infections are misleading.

5) Reportable, non-lost-time accidents occur at a frequency of approximately 100 per million man-hours worked.

6) Most laboratory infections occur to people who directly handle infectious materials. Laboratory technical assistants are the largest exposed group and have the largest number of accidents and infections. Students are often infected.

7) The parts of the body injured by laboratory accidents are typically distributed except that respiratory infections are abnormally high.

8) Although accident involvement is not usually influenced by the sex of the persons, younger persons and those with less technical training have more laboratory accidents than would be expected from their distribution in a typical exposed population.

9) The seasons of the year or the days of the week appear not to have an important or consistent influence on laboratory accident occurrence.

10) Although bacterial diseases in the laboratory are more frequent than those due to viruses, rickettsiae, and fungi, the importance of virus infections will probably increase as the science of virology expands. A significant proportion of laboratory infections do not show clinical symptoms and may remain undetected except by serological means.

11) Research activities are generally more hazardous than routine clinical laboratory work or teaching activities. However, when the number of people occupationally infected is compared with those potentially exposed, people at risk in educational institutions are at a disadvantage.

12) Non-utilization of modern design criteria for infectious disease facilities and failure to employ safety equipment contribute to the risk of injury and infection in many laboratory institutions. High construction costs are partly responsible for this There is no good evidence that limited space contributes to hazards in most laboratories, although the age of laboratory facilities was found to be inversely related to measurements of the adequacy of the safety programs carried on within them. Laboratory animal use in medical research tends to increase without equivalent increases in adequate and safe facilities.

13) Many laboratory hazards are well-known and easily recognized; others are not readily obvious and have been discovered only by laboratory research showing how the environment may be unknowingly contaminated with airborne infectious microorganisms. There is substantial lack of attention to both types of hazards, in spite of the fact that the human infectious dose levels for many diseases are very low.

14) The attitudes of Fort Detrick laboratory personnel were different from those of craft workers in a number of respects: laboratory workers often reject valued judgments concerning the safety program that are accepted by craft workers. For example, laboratory workers as a group were less confident that their supervisors reported all accidents, were less convinced of the value of safety regulations or of improved accident reporting, attached less importance to minor accidents, were more critical of the quality and quantity of the safety equipment, were less interested in safety councils, conferences, etc., and were less willing to report all illnesses. Laboratory workers tended to be conservative in subjective evaluations and bold in stating opinions that may conflict with well-known policy or regulation.

15) At infectious disease institutions, pathogenic materials may be expected to be involved in as many as one-half of the accidents. Biological accidents, as compared with industrial accidents, more frequently result in loss of work time. Typically, in microbiological laboratories, from 2.5 to 10.0 per cent of all accidents may result in lost-time injuries or infections.

16) Laboratory technicians and animal caretakers are involved in biological accidents twice as frequently as may be expected from their distribution in the exposed population. The 20- to 29-year-old group suffers an abnormal frequency of accidents. People with less technical training have higher than average accident frequencies. Females tend to have fewer biological accidents but have their expected share of injuries.

17) The most hazardous laboratory tasks leading to biological accidents are routine diluting, plating, and counting procedures and work with infected eggs; the most hazardous task associated with laboratory injuries is repairing or decontaminating laboratory rooms or buildings.

18) Most biological accidents potentially or actually produce injury to the respiratory system, thereby illustrating the need for suitable containment equipment. Most injuries occur to the fingers, thumbs, hands, and arms, therby signalling the need for proper protective clothing. The most common laboratory injury, lacerations, seldom results in loss of work time. Conversely, the most common type of biological accident, accidental inhalation, is the most frequent producer of infection. The most hazardous means by which laboratory employees contact injurious substances is by inhalation, absorption, or ingestion. Striking against objects and being struck by them are also important means of contact.

19) The most frequent mode of infection for laboratory exposures and infections is by inhalation of infectious aerosols. Although oral aspiration occurs infrequently, it is a serious accident.

20) Mechanical accident agencies are typically identified with approximately 95 per cent of the accidents, the most important being glassware and laboratory instruments and apparatus. That group of accidents not associated with mechanical agencies may contain an unusual number of lost-time accidents or infections.

21) Dried or lyophilized cultures, infected eggs, and aerosolized cultures are the most hazardous forms of infectious microorganisms for laboratory handling.

22) Unsafe acts cause more than three-quarters of all laboratory accidents. Handling equipment in an unsafe manner is the most frequent unsafe act. However, because one-half of the lost-time accidents result from unsafe acts not specifically identified, it is concluded that unsafe laboratory acts that are the most difficult to identify are the most serious in their potential of producing lost-time accidents or infections. Three common types of unsafe acts that have a high potential for

producing lost-time accidents are (i) removing, altering, or not using safety equipment, (ii) performing operations prohibited by regulations, and (iii) failure to wear proper protective devices.

23) As causes of laboratory accidents, unsafe acts and unsafe conditions are not mutually exclusive. The unsafe condition responsible for the greatest frequency of lost-time accidents is generally identified as hazardous process, operation, or arrangement. Equipment failure in the laboratory may be expected to be the cause of 10 per cent of the accidents. Although not a major cause, equipment failure is a significant cause of laboratory infections.

24) In accident cause determinations it is not unusual for accident investigators and others to underemphasize the importance of human error and overemphasize the importance of equipment failure. The imbalance may also be reflected in the corrective actions taken following accidents.

25) The five most frequently recognized causes of laboratory infections are animal bites, syringe inoculations, oral aspirations, sprays from syringes, and centrifuge accidents. Together these account for no more than 20 per cent of the laboratory infections, and explain the frequent statement that 80 per cent of laboratory infections are due to unknown causes.

26) From a variety of analyses and supporting data, it is concluded that the unknown causes of laboratory infections are primarily those of human error. These are, in fact, unsafe acts that are best described as transient mal-manipulations of infectious microorganisms that allow undetected escape of microbial aerosols and that are either not recognized by the worker or quickly forgotten. These are, in other words, "micro-scale" mistakes. Their elusive nature emphasizes the need for enclosing all infectious operations within ventilated cabinets and for assuring the proper use of the cabinets through education and enforcement.

27) Interview studies with Fort Detrick laboratory workers showed that an accident-free group differed from an accident-involved group with respect to use of tobacco, divorce rate, family size, and strength of family ties. Accident-free workers were more conservative in evaluating safety efficiency and tended to develop defensive work habits to a greater extent than accident-involved individuals. With accident-involved people, the lack of accident-perception ability and inflexibility of work habits were important cause factors. Moreover, accident-involved people were inclined toward excessive risk taking and intentional violation of safety regulations. The interview studies were in agreement with other analyses in regard to human error in accident causation; 82 per cent of the accident-involved persons performed unsafe acts. The interview studies showed that working at an abnormal rate of speed frequently causes laboratory accidents.

Human factors appeared as the most consistent common denominator in the causation of laboratory accidents. Accident-free persons more often appeared able to develop defensive work habits; accident-involved people tended to place excessive reliance on experience gained from accidents in avoiding later accidents. In role-playing situations, where each accident-free person was asked to give safety instruction to a person taking over his position, it was clear that most persons realized the importance of human factors. They admonished their replacements to avoid accident situations by obeying the safety regulations, and by having an awareness and respect for hazardous situations.

28) Finally, the group studies revealed that personal interviews brought to light many facts about accident experiences that had important relationships to accident causation but were not contained in the official accident records.

B. RECOMMENDATIONS

The recommendations derived from this research pertain, first, to the application of the data to the prevention of accidents and illness in laboratories handling infectious disease microorganisms, and, second, to areas where further safety research would be helpful. For both types of recommendations, it is appropriate to underscore the fact that changing emphasis in laboratory research, teaching, and diagnostic endeavors signals the dynamic nature of microbiological laboratory hazards. This is demonstrated by the current increased emphasis in virology compared with that of a decade ago. New diseases coming under investigation, new and different types of laboratory tests, and expanded laboratory teaching facilities are examples of developments that can be expected to create additional infectious hazards problems. Such problems will require increased attention to laboratory accident prevention principles developed from safety research. Because the present research has shown that the accident and illness potential in microbiological laboratories is of a sufficient order of magnitude to warrant attention, specific safety programs designed to control and eliminate these hazards are needed and justified.

1. Application of the Findings in Laboratory Safety Programs

In general, the accident cause information developed for laboratory accidents was not markedly different from the causal factors typical for all types of accidents. Safety engineering, for example, is required to provide safe laboratory apparatus, equipment, and protective devices, but education and enforcement are essential for safe use of this equipment. Moreover, unsafe acts are involved in most laboratory accidents, as in other types of accidents, and the importance of the conceptions, attitudes, and motivations of laboratory workers have an important bearing on safe performance.

In specific detail, there are some important differences in the causal factors of microbiological laboratory accidents as compared with other types of work accidents. These are primarily related to accident agencies such as pathogenic cultures, laboratory animals, and insects that are not normally otherwise present in the accident scene. Consideration of these factors has provided support for the concept that laboratory unsafe acts causing infections and accidents often occur on a micro-scale where their identification and therefore their elimination is difficult. In addition to the problem of identification of such causal factors, lack of accident-perception ability, inflexibility of work habits, intentional risk-taking, and working at abnormal rates of speed are significant causal factors to be considered in preventive programs.

Prevention of laboratory infections and accidents must begin with education. And for education to proceed, the single most important requirement is for the distribution, understanding, and acceptance of information on causal factors to administrators, laboratory directors, teachers, supervisors, and others responsible for planning, authorizing, or carrying out education and training.

In a campus situation, education takes on a double significance. This is because, ultimately, for the safety of the person in the laboratory, the responsibility rests in some way with the teaching institution that provided his initial training in laboratory science. Endowing the student with heuristic desires and technical knowledge is not enough. He must be taught how to use the instruments and apparatus of the laboratory. He must, in the educational process, be made to understand the importance of microbiological safety equipment and techniques, and be impressed with the notion that a good scientist is also a safe scientist. The educational system is, in fact, expected to produce professional people who have the knowledge and skills that will enable them to be continually effective in their chosen fields. It is in the school situation that most can be done toward making future laboratory scientists and technicians realize the role of microbiological safety in infectious operations. Accident and infection prevention should be presented and accepted as a natural part of laboratory life. The martyr-to-science concept of medical research wherein laboratory people accept accidental disease as a natural consequence of their profession cannot co-exist with modern safety education.

Therefore, the first step in the application of the causal data developed in this research is its acceptance and inclusion in laboratory science teaching and training programs. To supplement the data presented in this report, Appendix C presents a guide for student education in microbiological safety.

For the prevention of accidental infections, this research has emphasized the importance of achieving microbiological environmental control during all laboratory operations. This is because the single most important cause of infections is the accidental release of microbial aerosols at the laboratory working surface during the manipulation of cultures or animals. Microbiological environmental control endeavors should utilize the techniques of education, engineering, and enforcement to assure constant externalization of laboratory people from infectious materials. In this regard, it is of interest that microbiological environmental control will improve the validity of laboratory research results by preventing culture cross-contamination and animal cross-infection.

For a specific laboratory, the next step is to assess the extent of the accident problem or to estimate probable future problems. For this it is important to know the types of microorganisms used, their physical form, the nature of the laboratory tests, the conditions of supervision, and other related factors in order that they may be related to the causal factors developed here. Once there is an adequate assessment of the laboratory hazards and management is committed to the sponsorship of a preventive program, there should be evolved a precise personnel policy regarding occupational health. That is, management should make a series of policy decisions relating to the goals of the safety program and how it is to operate. By this action management makes it clear that no job will be considered so important that it cannot be done safely, and responsibility for accident prevention is established, including planning for safety control in all phases of laboratory work. Appendix D presents recommendations for the organizational elements of a laboratory safety program.

Laboratory accident control is best implemented by considering five important approaches that can be used. These are:

1) Management approach - selecting, training, regulating personnel; providing policy, reporting, and investigation methods; formulating safety regulations.

2) Vaccination of laboratory personnel when appropriate.

3) Use of safe techniques and procedures.

4) Use of safety equipment.

5) Laboratory design criteria.

The extent of use of each of these is determined by the extent of the laboratory hazards present and management's policy concerning them. Except for vaccination, the accident information developed in this research indicates the appropriate preventive measures under each of the above headings. For example, mouth pipetting of infectious or toxic fluids is not an acceptable technique because it is a common cause of laboratory infections. Likewise, the inability to detect or recognize micro-scale unsafe acts that release infectious aerosols emphasizes the importance of using ventilated microbiological safety cabinets. The possible problem of lack of accident-perception ability is approached by the teaching of typical situations that are likely to lead to accidents and infections. Understanding and utilization of appropriate criteria for the design of laboratories improves the containment of hazardous materials. Appendix E presents a typical list of laboratory safety rules based on the causal factors elicited by this research.

2. Recommendations for Further Research

The results of this research make it clear that microbiological laboratory accidents occur in the following general categories:

1) Those involving injuries, fires, and explosions, where the causes are not substantially different from those that exist in other work environments.

2) Those involving laboratory infection or infection combined with injury wherein the direct causes are readily identified and the requisite corrective actions are not difficult to recommend.

3) Those involving laboratory infections wherein the exact causes are not readily identified but are shown to be related to procedures that unknowingly release infectious aerosol to the worker's environment. The principal corrective action for these hazards involves the use of containment equipment such as ventilated cabinets.

Although these accident categories, their direct causes, and the resultant corrective actions are important, it is equally clear that underlying human factors impinge on the accident scene without regard to the accident category. It is in the area of human factors that additional research is needed. It is conceivable that in the future many aspects of our industrial civilization will be remotely controlled or automated to the extent that the human element of accidents is insignificant, but it seems unlikely that such developments will eliminate the human in laboratory research operations.

The entire spectrum of human factors research, however, is so broad, so all-inclusive, and requires contributions from so many disciplines that no immediate solution to the accident problem is likely to result from such research. Rather, it is to be expected that only gradually will we come to a reasonable understanding of how accidents can be efficiently reduced through the control of human factors. Moreover, whether a human factor be physiological, biochemical, or psychological, its relation to accident prevention is meaningless without reference to the specific environment and accident agencies present.[1]

For the specific environment of the infectious disease laboratory, the results of this research point to many typical interacting elements that impinge on human factors. The studies with groups of accident-involved and accident-free people also show some of the ways in which human factors relate to accident causation. However, it is clear that the findings and observations herein are only an initial attempt to understand human factors in relation to laboratory accidents.

Therefore, it is concluded that the most important type of future research needed for improved understanding of laboratory accident prevention is in the area of human

[1] L. Brody, "Human Factors Research in Occupational Accident Prevention," Center for Safety Education, New York University, (1962), p. 3.

factors research. Most of the needed equipment for laboratory safety has been designed. Many of the hazardous techniques have been identified and their relative order of hazard understood. Many epidemiological facts related to the age, sex, occupation, etc. of accident-involved individuals have been studied. These findings presently provide a sufficient basis for improving safety in most laboratory institutions, if for no other reason than the fact that the engineering approach to safety has not as yet found common acceptance. But it has been adequately demonstrated also that this approach alone is no panacea. Continued improvements will depend on the results of in-depth investigations on human factors.

Just as in all areas of accident occurrence, a recommended base for investigating human factors in laboratory accidents is found in the concept of human stress and stress reaction.[1] What amount of individual stress is necessary to combat complacency in the handling of highly infectious disease agents? What amount of stress or what conditions and training are needed to develop defensive work habits that protect an individual from accident involvement? Following a laboratory infection, what physiological or psychological stresses result that affect a person's subsequent safety performance? Does the philosophy of scientific freedom characterized by research activities contribute to undesirable stresses when safety programs require considerable attention to inspections, accident investigations, and regulatory requirements? These are typical examples of possible human factors research based on human stress reactions.

[1]L. Brody, "Methodology and Patterns of Research in Industrial Accidents," Annals of the New York Academy of Sciences, 107 (1963), pp. 659-663.

BIBLIOGRAPHY

Accident Facts. 1963 Edition, National Safety Council, 425 N. Michigan Ave., Chicago, 96 pp.

Accident Prevention Manual. (2nd ed.), National Safety Council, (1951), pp. 17-25.

Albrecht, J., "Danger Due to Infectious Aerosols in the Laboratory." in Fort der Biologischen Aerosol-Forschung by H. Nuckel, Friedrich-Karl Schattauer-Verlag, Stuttgart, Germany, (1961), pp. 148-153.

American Recommended Practice for Compiling Industrial Accident Causes, Part I. "Selection of Accident Factors." New York: American Standards Association, Z16.2 (1941).

American Standard Method of Recording and Measuring Work Injury Experience. Z.16.1, American Standards Association: New York, (1954).

Anderson, R.E., Stein, L., Moss, M.L., and Gross, N.H., "Potential Infectious Hazards of Common Bacteriological Techniques." Journal of Bacteriology, 64 (1952), pp. 473-481.

"Animal Facilities in Medical Research." ILAR Report, National Research Council, Washington, D. C., (May 1962), pp. 35-36.

"Attitudes Toward Safety at the Biological Warfare Laboratories." Operation Evaluation Report, PMB Report 48-58-A, Personnel Management Branch, The Adjutant General, Dept. of the Army, (1959), 73 pp.

Barbeito, M.S., Alg, R.L., and Wedum, A.G., "Infectious Bacterial Aerosol from Dropped Petri Dish Cultures." American Journal Medical Technology, 27 (1961), pp. 318-322.

Bloom, B., "The Hazard of Orally Pipetting Tritium Oxide." Journal of Laboratory and Clinical Medicine, 55 (1960), p. 164.

Boyd, M.F., and Kitchen, S.F., "On Attempts to Hyperimmunize Convalescents from Vivax Malaria." American Journal Tropical Medicine, 23 (1943), pp. 209-225.

Breed, R.S., Murray, E.G.D., and Smith, V.R., Bergey's Manual of Determinative Bacteriology. (Seventh ed.), Baltimore: The Williams and Wilkins Co., 1957.

Brody, L., "Human Factors Research in Occupational Accident Prevention." Center for Safety Education, New York University (1962), 44 pp.

Brody, L., "Methodology and Patterns of Research in Industrial Accidents." Annals of the New York Academy of Sciences, 107 (1963), pp. 659-663.

Bunge, M., "Causality, Chance, and Law." American Scientist, 49 (1961), pp. 432-448.

Chatigny, M.A., "Protection Against Infection in the Microbiological Laboratory: Devices and Procedures." In: Advances in Applied Microbiology, Vol. 3. edited by Wayne W. Umbreit, Academic Press, New York, 1961.

Cluff, L.E., Trever, R.W., Imboden, J.B., and Canter, A., 'Brucellosis, II. Medical Aspects of Delayed Convalescence." Archives Internal Medicine, 103 (1959), pp. 398-405.

Commission on Acute Respiratory Disease, Fort Bragg, N. C., "A Laboratory Outbreak of Q Fever Caused by the Balkan Grippe Strain of Rickettsia burnetii." American Journal Hygiene, 44 (1946), pp. 123-157.

Cook, E.B.M., "Safety in the Public Health Laboratory." Public Health Reports, 76 (1961), pp. 51-57.

Davison, G., Neubauer, C., and Hurst, W.W., "Meningo-Encephalitis in Man Due to the Louping-Ill Virus." Lancet, 2 (1948), pp. 453-457.

Draese, K.D., "Uber Laboratoriumsinfektionen mit Typhusbazillen und Anderen Bakterien." Archives fur Hygiene und Bacteriology, 119-121 (1937-1939), pp. 232-291.

Dickie, H.A., and Murphy, M.E., "Laboratory Infection with Histoplasma capsulatum." American Review Tuberculosis, 72 (1955), p. 690.

Dyer, R.E., "Filter-Passing Infectious Agent Isolated from Ticks. Human Infections." Public Health Reports, 53 (1938), pp. 2277-2282.

Editorial: "Laboratory Infections." Lancet, 2 (1956), pp. 880-881.

Eyles, D.E., Coatney, G.R., and Getz, M.E., "Vivax-Type Malaria Parasite of Macaques Transmissible to Man." Science, 131 (1960), pp. 1812-1813.

Fox, B.H., Behavioral Approaches to Accident Prevention. Association for the Aid of Crippled Children, New York, N. Y., (1961), p. 51.

Gordon, J.E., "The Epidemiology of Accidents." American Journal Public Health, 39 (1949), pp. 504-515.

Hanel, E.,Jr., "Laboratory-Acquired Mycotic Infection." In manuscript.

Hedvall, E., "The Incidence of T.B. Among Students at Lund University." American Review Tuberculosis, 41 (1940), pp. 770-780.

Held, J.R., "Sub-Human Primates in the Transmission of Human Hepatitis." Sixth CDC Biennial Veterinary Conference, Atlanta, Georgia, August 6-10, 1962.

Hornibrook, J.W. and Nelson, K.R., "An Institutional Outbreak of Pneumonitis. I. Epidemiological and Clinical Studies." Public Health Reports, 55 (1940), pp. 1936-1954.

Howe, C., Miller, E.S., Kelly, E.H., Bookwalter, H.I., and Ellingson, H.V., "Acute Brucellosis Among Laboratory Workers." New England Journal Medicine, 236 (1947), pp. 741-747.

Huddleson, I.F., and Munger, M., "A Study of an Epidemic of Brucellosis Due to Brucella melitensis." American Journal of Public Health, 30 (1940), pp. 944-954.

Huebner, R.J., "Report of an Outbreak of 'Q' Fever at National Institutes of Health." American Journal Public Health, 37 (1947), pp. 431-440.

Imboden, J.B., Canter, A., Cluff, L.E., and Trever, R.W., "Brucellosis, III. Psychologic Aspects of Delayed Convalescence." Archives Internal Medicine, 102 (1959), pp. 406-414.

Kirchheimer, W.F., Jemski, J.V., and Phillips, G.B., "Cross-Infection Among Experimental Animals by Organisms Infectious for Man." Proceedings Animal Care, 11 (1961), pp. 83-92.

Kisskalt, A., "Laboratoriuminfektionen mit Typhusbasillen und Anderen Bakterien." Archives fur Hygiene, 101 (1929), pp. 137-160.

Kisskalt, A., "Laboratory Infections with Typhoid Bacilli." Zeitschrift fur Hygiene und Infektionskrankheiten, 80 (1915), pp. 145-162.

Kruse, R.H., "Potential Aerogenic Laboratory Hazards of Coccidioides immitis." American Journal Clinical Pathology, 37 (2), (1962), pp. 150-158.

Leonard, A.R., "An Epidemiologic Approach to Health Education." American Journal of Public Health, 51 (1961), pp. 1555-1560.

Ley, H.L.,Jr., Smadel, J.E., Diercks, F.H., and Paterson, P.Y., "Immunization Against Scrub Typhus, V. The Infective Dose of Rickettsia tsutsugamushi for Men and Mice." American Journal Hygiene, 56 (1952), pp. 313-319.

Lim-Yuen, D.M., "Tuberculosis in Sanatorium Personnel." American Review of Tuberculosis, 54 (1946), pp. 261-271.

Loffler, W., and Mooser, H., "Mode of Transmission of Typhus Fever: Study Based on Infection of Group of Laboratory Workers." Schweizerische Medizinische Wochenschrift, 72 (1942), pp. 755-761.

Love, F.M., and Jungherr, E., "Occupational Infection with Virus B of Monkeys." Journal American Medical Association, 179 (1962), pp. 804-806.

Lurie, M.B., "The Prevention of Natural Airborne Contagion of Tuberculosis in Rabbits by Ultraviolet Irradiation." Journal Experimental Medicine, 79 (1944), pp. 559-572.

Magnuson, H.J., Thomas, E.W., Olansky, S., Kaplan, B.I., De Mello, L., and Cutler, J.C., "Inoculation Syphilis in Volunteers." Medicine, 35 (1956), pp. 33-82.

Malfetti, J.A., "Attitudes and Safety in Recreation." Public Health Reports, 78 (1963), pp. 477-485.

McCoy, G.W., "Accidental Psittacosis Infection Among the Personnel of the Hygienic Laboratory." Public Health Reports, 45 (1930), pp. 843-845.

McCullough, N.B., and Biseli, C.W., "Experimental Human Salmonellosis." Journal Infectious Diseases, 88 (1951), pp. 278-289.

McFarland, R.A., "Epidemiologic Principles Applicable to the Study and Prevention of Child Accident." American Journal of Public Health, 45 (1955), pp. 1302-1308.

McFarland, R.A., "The Epidemiology of Accidents." In Accident Prevention, ed. by M. N. Halsey, (1961), McGraw-Hill Book Co., Inc., New York, pp. 17-45.

Meade, G.B., "The Prevention of Primary Tuberculosis Infections in Medical Students." American Review Tuberculosis, 58 (1948), pp. 675-683.

"Medical School Facilities, Planning Considerations and Architectural Guide." U.S. Public Health Service Publication 875 (1961), pp. 112-118.

Merger, C., "Hazards Associated with the Handling of Pathogenic Bacteria." Canadian Journal Laboratory Technology, 18 (1957), pp. 208-210.

Meyer, K.F., and Eddie, B., "Laboratory Infections Due to Brucella." Journal Infectious Diseases, 68 (1941), pp. 24-32.

Morris, S.I. "Tuberculosis As An Occupational Hazard During Medical Training." American Review of Tuberculosis, 54 (1946), pp. 140-158.

Murray, J.F., and Howard, D., "Laboratory-Acquired Histoplasmosis." American Review of Respiratory Diseases, 89 (1964), pp. 631-640.

Nauck, E.G., and Weyer, F., "Laboratory Infections with Q Fever." Deutsche Medizinische Wochenschrift, 7 (1949), pp. 198-202.

Nicolas, M.J., "Sur un Cas de Tetanus Chez I'Homme par Inoculation Accident des Produits Solubles due Bacilli de Nicolaier." Compes Rendus des Seances de la Societe de Biologie, 5 (1893), pp. 844-847.

Paneth, L., "The Prevention of Laboratory Infections." Medizinische Klinik, 11 (1915), pp. 1398-1399.

Phair, J.J., and Sterling, T., "Epidemiological Methods and Community Air Pollution." Archives of Environmental Health, 3 (1961), pp. 267-275.

Phillips, G.B., "Microbiological Safety in U. S. and Foreign Laboratories." Technical Study 35, U.S. Army Chemical Corps Biological Laboratories, Fort Detrick, Frederick, Maryland (September, 1961), 291 pp.

Phillips, G.B., "Programming for Infectious Disease Animal Facilities." Presented at the Symposium on Research Animal Housing sponsored by the National Research Council, Washington, D. C. (November 16-17, 1962).

Phillips, G.B., and Jemski, J.V., "Biological Safety in the Animal Laboratory." Laboratory Animal Care, 13 (1963), pp. 13-20.

Pike, R.M., Sulkin, S.E., and Schulze, M.L., "Continuing Importance of Laboratory-Acquired Infections." Presented at the annual meeting of the American Public Health Association, St. Louis, Mo., November 14, 1963.

"Planning and Design of Medical Research Facilities." National Institutes of Health, Division of Research Services, Bethesda 14, Md., (1962), pp. 6-10.

Reid, R.D., "Trends in Microbiology." American Institute of Biological Sciences, Bulletin No. 1956.

Reid, D.D., "Incidence of Tuberculosis Among Workers in Medical Laboratories." British Medical Journal, 2 (1957), pp. 10-14, 35-36.

Reitman, M., Phillips, G.B., Alg, R.L., and Hanel, E.,Jr., "Biological Hazards of Common Laboratory Techniques, I-IV." American Journal of Medical Technology, 21, 22 (1955-1956), pp. 338-346, pp. 14-17.

Reitman, M., and Wedum, A.G., "Microbiological Safety." Public Health Reports, 71 (1956), pp. 659-665.

Revich, S.J., Walker, A.W., and Pivnick, H., "Human Infection by Brucella abortus Strain 19." Canadian Journal of Public Health, 52 (1961), pp. 285-289.

Rivers, T.M., and Horsefall, F.L., Viral and Rickettsial Infections of Man, (Third ed.), Philadelphia: J. B. Lippincott Co., (1959).

Robbins, F.C., and Rustigan, R., "Q Fever in the Mediterranean Area: Report of Its Occurrence in Allied Troops, IV. A Laboratory Outbreak." American Journal Hygiene, 44 (1946), pp. 64-71.

Sabin, A.B., and Wright, A.M., "Acute Ascending Myelitis Following Monkey Bite with Isolation of Virus Capable of Reproducing Disease." Journal Experimental Medicine, 59 (1934), pp. 114-136.

Saslaw, S., Eigelsback, H.T., Wilson, H.E., Prior, J.A., and Carhart, S., "Tularemia Vaccine Study. I. Intracutaneous Challenge. II. Respiratory Challenge." Archives Internal Medicine, 107 (1961), pp. 689-714.

Schafer, W., "Laboratory Infections Especially with Typhoid Bacilli." Archives fur Hygiene und Bakteriology, 132 (1950), pp. 15-32.

Schwarz, J., Baum, G.L., and Evans, N.A., "Clinical Reports of a Case of Blastomycosis of the Skin From Accidental Inoculation." Journal American Medical Association, 40 (1903), pp. 1772-1775.

Simonds, R.H., and Grimaldi, J.V., Safety Management, Homewood, Illinois: Richard D. Irwin, Inc., (1956), 555 pp.

Slepushkin, A.N., "Epidemiological Study of a Laboratory Infection with the Venequelan Equine Encephalomyelitis Virus." Voprosy Virusologii (USSR), 4 (1959), pp. 311-314.

Smith, C.E., "The Hazard of Acquiring Mycotic Infections in the Laboratory." An Address Delivered Before the Epidemiology and Laboratory Sections, American Public Health Association Meeting, St. Louis, Missouri, (November 2, 1950).

Smith, C.H., "Accidental Laboratory Infection with Trachoma." British Journal Ophthalmology, 42 (1958), pp. 721-722.

Smith, D.G., Mamay, H.K., Marshall, R.G., and Wagner, J.C., "Venezuelan Equine Encephalomyelitis." American Journal Hygiene, 63 (1956), pp. 150-164.

Smith, G.S., "Tuberculosis as a Necropsy Room Hazard." Journal Clinical Pathology, 6 (1953), pp. 132-134.

Snow, D.L., "Principles of Space Planning for Biomedical Research Laboratories." National Institutes of Health, Division of Research Services, Bethesda 14, Md., (1962), 56 pp.

Southam, C.M., and Moore, A.E., "Induced Virus Infections in Man by the Egypt Isolates of West Nile Virus." American Journal Tropical Medicine and Hygiene, 3 (1954), pp. 19-50.

Sulkin, S.E., "Laboratory-Acquired Infections." Bacteriological Reviews, 25 (1961), pp. 203-209.

Sulkin, S.E., Burns, K.F., Shelton, D.F., and Wallis, C., "Bat Salivary Gland Virus: Infections of Man and Monkey." Texas Reports on Biology and Medicine, 20 (1962), pp. 113-127.

Sulkin, S.E., Pike, R.M., Long, E.R., Smith, C.E., Sigel, M.M., and Wedum, A.G., "Laboratory Infections and Accidents." in Diagnostic Procedures and Reagents (4th ed.), American Public Health Association, New York, (1963).

Sulkin, S.E., and Pike, R.M., "Survey of Laboratory Infections." American Journal Public Health, 41 (1951), pp. 769-781.

Sulkin, S.E., and Pike, R.M., "Viral Infections Contracted in the Laboratory." New England Journal Medicine, 241 (1949), pp. 205-213.

Sutton, L.S., and Brooke, C.C., "Venezuelan Equine Encephalomyelitis Due to Vaccination in Man." Journal American Medical Association, 155 (1954), pp. 1473-1476.

Tigertt, W.D., and Benenson, A.S., "Studies of Q Fever in Man." Journal Association American Physicians, 69 (1956), pp. 98-104.

Trever, R.W., Cluff, L.E., Peeler, R.N., and Bennett, I.L.,Jr., "Brucellosis, I. Laboratory-Acquired Infection." Archives Internal Medicine, 103 (1959), pp. 381-397.

Van Metre, T.E., Jr., and Kadull, P.J., "Laboratory-Acquired Tularemia in Vaccinated Individuals: A Report of 62 Cases." Annals of Internal Medicine, 50 (1959), pp. 621-632.

Wadsworth, A., Langworthy, H.V., Stewart, F.C., Moore, A.C., and Coleman, M.G., "Infectious Jaundice Occurring in New York State." Journal American Medical Association, 78 (1922), pp. 1120-1121.

Weathersby, A.B., "One-Hand Manipulator for Hypodermic Syringes." American Journal of Clinical Pathology, 36 (1961), p. 94.

Wedum, A.G., "Bacteriological Safety." American Journal Public Health, 43 (1953), pp. 1428-1437.

Wedum, A.G., "Control of Laboratory Airborne Infection." Bacteriological Reviews, 25 (1961), pp. 210-216.

Wedum, A.G., "Health Hazards in Laboratories and Research Areas," Safety Monographs for Colleges and Universities, 7 (1957), pp. 15-20, National Safety Council, 425 N. Michigan Ave., Chicago 11, Illinois.

Wedum, A.G., "Laboratory Safety in Research with Infectious Aerosols." Public Health Reports, 79 (1964), pp. 619-633.

Wedum, A.G., "Nonautomatic Pipetting Devices for the Microbiologic Laboratory." Journal of Laboratory and Clinical Medicine, 35 (1950), pp. 648-651.

Wedum, A.G., "Policy, Responsibility and Practice in Laboratory Safety." Proceedings Second Symposium on Gnotobiotic Technology, University of Notre Dame Press, Notre Dame, Indiana, (1959), pp. 105-119.

Wedum, A.G., and Phillips, G.B., "Criteria for Design of a Microbiological Research Laboratory." American Society Heating, Refrigerating, and Air Conditioning, 6 (1964), pp. 46-52.

Wolff, J.W., Bohlander, H., and Ruys, A.C., "Researches on Leptospirosis Ballum: The Detection of Urinary Carriers in Laboratory Mice." _Antonie V. Leeuwenhock_, 15 (1949), pp. 1-13.

"Work Injuries and Work Injury Rates in Hospitals." U. S. Dept. Labor, Bureau Labor Statistics, _Bulletin No. 1219_, (February 1958).

APPENDIX A

SAFETY INTERVIEW OUTLINE

Interview Number:

Date:

Questions for All Subjects

1. Age
2. Sex
3. Pay grade or military rank
4. Marital status and number of children
5. Education and degrees
6. Occupational classification
7. Years of government service
8. Amount of unused sick leave and annual leave
9. Previous professional experience
10. General physical condition, weight, and height
11. Prosthetic or corrective devices used (Braces, trusses, hearing aids, eye glasses)
12. Presence of dizzy spells, nervous spells, severe headaches, heart ailment, diabetes, seizures of any sort, or other conditions
13. Date and place of last physical examination and results
14. Date and nature of last illness requiring a doctor's care
15. Do you take any of the following? How often?

insulin	antihistamines	barbiturates
benzedrine	tranquilizers	other

16. Do you drink alcoholic beverages? How often? How much?
17. Do you smoke? Cigars, cigarettes, or pipe? Packs per day of cigarettes?
18. Are you against smoking or drinking?
19. Examples of types of laboratory work performed
20. Number, types, and outcomes of previous recorded minor accidents

21. Details of laboratory-acquired infections

22. Details of lost-time laboratory injuries

23. How did you learn about microbiological safety?

24. What is your career goal or ambition?

25. What is your favorite recreation?

26. What is your hobby?

27. Describe any serious off-the-job accidents that have occurred to you.

28. List number and nature of automobile accidents you have been involved in and number and type of traffic violation convictions.

29. Do you own your home? Rent? Buying your home?

30. Describe any non-reported close calls or near accidents you have had on the job.

31. Do you think that having an accident makes you more or less likely to have another accident of the same type?

32. Is safety a worthwhile endeavor?

33. In the laboratory what do you think is the most important means of achieving safety?

34. Which of the following do you think is the most important?

    Careful techniques, safety equipment, efforts by safety personnel, or proper attitude.

35. Do you have any suggestions on how we can improve safety in the microbiological laboratory?

36. What irritates you most about the safety program? Explain.

37. How do you feel about our safety regulations?

38. How do you feel about the manner in which safety personnel handle your problems?

39. How do you feel about the safety supervision you get at different levels?

40. Would you say that the amount of emphasis on safety here is too much, too little, or about right?

41. What techniques designed to promote the safety program are the best in your opinion?

42. What techniques are the worst?

43. Which of the following stimulate your thinking the most? List them in order starting with the most effective:

    posters, published regulations, safety meeting, safety bulletins, training programs, inspections, personal experience from previous accidents.

44. What steps would you like to see taken to improve safety in your laboratory?

45. What steps would you take if you had unlimited funds and authority?

46. Is it desirable to eliminate all hazards from our daily lives?

47. How would you rate working conditions on your job?

48. Evaluate the following statements:

    a. My supervisor is fair to all of us.
    b. My supervisor assumes his responsibilities.
    c. My supervisor keeps his promises.
    d. My supervisor keeps us informed.
    e. My supervisor gives credit where credit is due.

49. How does your wife or family feel about your working at Fort Detrick?

50. What do you think would be the effect of having more social and recreational affairs at Fort Detrick?

51. Evaluate: "The Biological Laboratory is a safe place to work."

52. How often do you feel that working surfaces, equipment, and labs should be disinfected?

53. How do you feel about the safety equipment that is available for your use?

54. Could your job be accomplished as safely if some of the safety rules and procedures were eliminated?

55. How do you feel about taking short cuts or deliberate risks?

56. Do you feel your co-workers are safety-conscious while on their jobs?

57. If one of your co-workers was careless about safety regulations what would be the reaction of the rest of the group?

58. Some of the workers you know may ignore one or more of the safety regulations. Why do you think they do this?

59. Do you know of safety rules or procedures that are followed in your area and should be but are not followed by persons in other areas?

60. Do you know of safety rules that are followed by persons in other areas and should be but are not followed by persons in your work area?

61. What portion of all accidents that occur in your organization do you feel are reported?

62. Evaluate: "Accidents that don't seem to be important when they happen, often bring about infectious diseases."

63. What do you think is the most common cause of the laboratory illnesses at the Biological Laboratories?

64. What part of the "unknown" causes of illnesses do you feel would become "known" if everyone reported everything they knew about accidents and exposures?

65. How many times in the past 12 months do you feel an incident occurred where you were exposed unnecessarily to an infection?

66. What would you do if you did not feel well and suspected an infection?

67. Do you feel that the immunizations are effective?

68. How does your supervisor feel about letting the workers use unsafe short cuts?

69. Does your immediate supervisor encourage the reporting of minor accidents?

    a. Yes, all of the time.
    b. Most of the time.
    c. Seldom.
    d. Never.

70. Evaluate:

    a. The Laboratory Safety Council
    b. The Post Safety Council
    c. The Post Safety Division Staff
    d. Safety Lectures and Conferences

71. Evaluate: "The safety personnel are fair and just in their dealings with the workers."

72. If you were starting all over, would you work at Fort Detrick again?

73. How do you feel about this interview?

<u>Questions for Accident-Involved Persons</u>

1. Date, time, and location of accident.

2. Other persons present

3. Type of accident

4. What do you think caused the accident?

5. Were there other possible causes?

6. Did you foresee that the accident was going to happen?

7. Could a different reaction on your part have prevented the accident or reduced its severity?

8. What were you thinking about just before the accident?

9. What did you do to try to avoid the accident when you realized it was going to happen?

10. Were you working at an abnormal rate of speed?

11. Were there any distractions that contributed to the accident?

12. How were the room conditions at the time of the accident?
    a. Could you see well?
    b. Was it too hot or too cold in the room?
    c. Other?

13. What did you do immediately after the accident?

14. Should you have acted differently?

15. To your knowledge was there a violation of a safety regulation involved?

16. If so, is this regulation reasonable? Should it be revised? In what way?

17. What was the next thing that happened after the accident?

18. Was this accident like any you had had before?

19. The night before the day of the accident
    a. Did you sleep well?
    b. How many hours of sleep - more or less than usual?
    c. Did you "go out" that evening?
    d. Did you drink any alcoholic beverages?

20. What in general did you do on the day of the accident from the time you arose to the time you had the accident? Was this different from your usual activities? How?

21. Before the accident, were you drowsy, tired, nervous or upset, bored, excited, elated, angry, dejected, in a hurry, or other? Why?

22. Is there anything else you would like to say about this accident?

Questions for Accident-Free Persons

1. Insofar as your own laboratory work is concerned, what is your personal philosophy or code that you feel helps you to remain accident-free?

2. Do you feel that an accident-free work record is something to be proud of?

3. Which of the following have been important to you, personally, in maintaining an accident-free record? List in order of importance to you.
    a. The safety regulations
    b. Safety lectures or films you have seen
    c. Training and guidance by your supervisor
    d. Participation in safety meetings, on committees, etc.
    e. Safety equipment such as cabinets, etc.
    f. Discussions with Safety Division personnel
    g. Reports and publications on laboratory hazards
    h. Safety support from top management

4. Which of the above have been of no value?

5. What specific suggestions could you give another person in your job that may improve his accident record?

APPENDIX B

ACCIDENT CLASSIFICATION OUTLINE

1. Sex of person
   - Male
   - Female

2. Age

3. Job classification:
   - Laboratory technical assistant
   - Trained scientific person
   - Animal caretaker
   - Dishwasher
   - Janitor
   - Administrative or clerical
   - Maintenance
   - Visitor

4. Building and division

5. Type of laboratory
   - Bacteriology
   - Virology
   - Mycology
   - Pathology
   - Aerobiology
   - Clinical
   - Other

6. Date and time of accident

7. Accident outcome
   - No injury or infection
   - Non-lost-time injury
   - Non-lost-time infection
   - Lost-time injury
   - Lost-time infection
   - Fatal injury
   - Fatal infection

8. Days lost

9. Accident class
   - Industrial or chemical
   - Biological
   - Combined biological and industrial

10. Task being performed
    - Inoculating, harvesting eggs
    - Routine diluting and plating
    - Handling bulk infectious cultures
    - Packaging, transporting cultures
    - Moving heavy lab. equipment
    - Chemical tests and titrations
    - Repairing, decontaminating rooms
    - Feeding, transporting animals, cleaning cages, etc.
    - Exposing, injecting, autopsying animals
    - Aerobiological experiments
    - Washing, cleaning glassware
    - Other

11. Biological agencies
    - Liquid cultures
    - Surface colonies
    - Infected eggs
    - Tissue cultures
    - Frozen cultures
    - Generated aerosols
    - Direct or lyophilized material
    - Infected live animals
    - Infected animal tissues
    - Other

12. Chemical agencies
    - Flammable substances
    - Liquid toxic chemicals
    - Vapor of toxic chemicals
    - Hot solutions
    - Other

13. Mechanical agencies
- Laboratory glassware
- Containers, cases, etc.
- Gloves
- Syringes and needles
- Ventilated cabinets and systems
- Autoclaves and sterilizing chambers
- Pipes, valves, plumbing
- Animal cages and racks
- Electrical apparatus
- Laboratory hand tools
- Non-powered shop tools
- Ventilated personnel hoods and suits
- Filter plenums
- Sonic vibrators
- Other
- Ventilation systems
- Refrigerators and deep freezes
- UV lamps
- Centrifuges
- Autopsy instruments
- Pipettes
- Floors
- Stairs
- Powered shop tools
- Table tops and working surfaces
- Walls
- Conveyors
- Tissue grinders
- Elevators
- Unknown

14. Possible or actual mode of infection or exposure
- Inhalation
- Direct inoculation
- Skin contamination
- Ingestion

15. Body part involved
- Head and face
- Eyes
- Back
- Chest
- Arms
- Hands
- Fingers and thumbs
- Legs
- Feet
- Toes
- Other

16. Nature of injury
- Laceration
- Contusion
- Eye injury
- Burn
- Strain or sprain
- Chemical exposure
- Biological exposure
- Dermatitis
- Fracture
- Other

17. Manner of contact with injurious substance
- Striking against
- Being struck by
- Slip or overexertion
- Caught in or between
- Fall from same level
- Contact, extreme temperature
- Contact, UV radiation
- Contact, electric current
- Inhalation, absorption, or ingestion
- Fall from different level

18. Unsafe acts
- Handling equipment in an unsafe manner
- Use of unsafe or improper equipment
- Operating at unsafe speeds
- Failure to wear proper protective devices
- Dropping cultures
- Performing operations prohibited by regulation
- Removing, altering, not using safety equipment
- Miscellaneous
- Unknown

19. Unsafe conditions

Defective condition of equipment or apparatus
Hazardous process, operation, or arrangement
Unsafe dress or apparel
Unsafe design or construction of equipment or apparatus
Inadequate guarding
Use of wrong type of equipment or aratus
Leaking or nontight equipment
Inadequate or incorrect illumination
Inadequate or incorrect decontamination equipment
Inadequate or incorrect ventilation or filtration
Miscellaneous
None

20. Stated cause of accident

Employee at fault
Equipment faulty or failed
Supervisor at fault
Combined human and equipment failure
Another work group at fault
Unknown

21. Corrective action taken

Employee warned, advised, cautioned
Employee retrained or reinstructed
Equipment replaced or repaired
Warning devices, guards, etc., installed
Inspection or testing procedures instituted
Area decontaminated or sterilized
New safety equipment ordered or designed
Procedure changed or modified
Procedure eliminated
None

APPENDIX C

GUIDES FOR STUDENT EDUCATION IN MICROBIOLOGICAL SAFETY

A. TEACHING METHODS

1. Presentation of fundamental and background material through classroom lectures.

2. Use of training films and other visual aids that demonstrate general and specific laboratory procedures to be followed.

3. Laboratory instruction where the student learns more about procedures, equipment, and facilities necessary for adequate safety and practices the required techniques.

4. Where individual student practice is impracticable, laboratory demonstrations can be used to illustrate certain procedures and practices.

5. Study by students of current literature on laboratory technology and safety. Current text books on microbiology are beginning to include information of this type. Other information is contained in various journals in the field. Study of a typical set of laboratory safety regulations is recommended.

6. Learning can also be accomplished through the assignment of student projects and theme subjects related to microbiological safety. Or the instructor can insist that all student projects and term papers include an outline of the hazards that might be expected and means of controlling or eliminating infectious risks.

B. TEACHING OBJECTIVES

The general aims of instruction in microbiological safety are listed below.

1. To create a general understanding of the broad aspects of safety so that the student can more readily understand how laboratory safety fits into the concept of an accident-free existence.

2. To maintain, during the education of the student, technical knowledge, procedural, and safety efficiency at the same level. A deficiency in any of these three elements is obviously undesirable to the graduate.

3. To enable the future professional person to be mentally, physically, and technically qualified for his position in society.

4. To destroy any common illusions that may exist concerning the degree to which microbiologists and medical scientists are obligated to accept the "risks of the trade."

Specific objectives for the teaching program are essentially the same as objectives pertinent in other phases of safety education.

1. To develop an understanding of the work hazards peculiar to laboratory manipulations with disease-producing microorganisms.

2. To teach methods of eliminating these occupational risks.

3. To teach methods of compensating for hazards when removal is impractical or impossible.

4. To impress upon students the necessity of designing safety into new research methods that may be developed and the need to avoid combinations of laboratory activities that may create hazards.

C. TEACHING SCOPE

In the undergraduate study of microbiology or in pre-medicine, the student may be required to take from 5 to 10 courses in which microorganisms are handled. In medical school or in pursuit of other higher technical degrees he will take other specialized courses in microbiology. Although it is possible to design a separate teaching course for microbiological safety, in most instances this will be determined to be administratively and technically impractical. Not only would this force an additional course into schedules that are already overcrowded, but deciding where within the 4- to 7-year period of training to utilize the safety course would be difficult. Presenting a separate safety course lacks real significance, since it would either be behind or ahead of the student's technical competence.

A better plan is to integrate the teaching of safety with all of the courses in microbiology. Since the types of courses offered vary widely, no attempt will be made to specify a course-wise division of material. It will be obvious, however, that much of the basic and background material, as well as instructions in general techniques, should be given in the beginning courses. Subsequent courses will incorporate safety material of a more specific nature as the exact subject matter of the course dictates. Continuous integration in all courses will insure that proper work habits and attitudes are developed.

D. TRAINING TEACHERS

It is evident that after instruction in microbiological safety is firmly established in the curriculum, the training necessary for teachers becomes a self-accomplishing task; however, initial instruction of teachers may be difficult. It is being aided in a variety of ways by present-day trends in microbiology and medicine, in which the importance of environmental control and experiment validity are being emphasized.

Preparation and distribution of suggested teaching material and programs will aid in the training of teachers once the current trends become evident and once the responsibility for safety instruction is recognized. Available research literature, surveys, films, and books will help the teacher prepare himself in this area. Discussions at local, national and international meetings, seminars, and conferences will also be of assistance.

E. PHILOSOPHY AND PSYCHOLOGY OF SAFETY

Information for lecture material on general safety subjects can be obtained from textbooks on safety education. It is recommended that the basic subject area be covered without particular emphasis on the microbiological applications. Some concept of the basic aspects formulated by experts in the broad field of safety education is necessary for a realistic understanding by students of the relative position of microbiological safety.

The amount of detail presented is secondary to the purpose of bringing about in the student a feeling for accident prevention and a realization that accidents are frequently a product of a life not well organized. "Safety as an educational factor cannot be separated from education as a whole...."[1]

The extent to which some of the orientation lecture material may be covered in other college courses will, of course, determine how it is handled in the microbiology courses. Usually, in undergraduate schools, there are one or more courses that all students must take regardless of their major study field. Including units on the philosophy or psychology of safety in such courses may be appropriate.

The following outline is presented for the instructor's consideration and use in conjunction with authoritative tests on this subject.

Philosophy of Safety

1. What are the goals of safety?
2. Accidents are a consequence of a sequence of events.
3. Results of accidents are deaths, major injuries, infections, minor injuries, or near misses.
4. Who is responsible for safety?
5. Who pays for safety?
6. The importance of a positive concept.
7. The concept of environmental control.

Psychology of Safety

8. Elements acting in accident situations.
9. Human factors as causes of accidents.
10. The role of attitudes, emotions, and perceptions.
11. Learning safe behavior.

Definitions

12. Accidents.
13. Unsafe acts and unsafe conditions.
14. Summary of the purposes of accident prevention instruction.

F. VISUAL AID TEACHING MATERIALS

A number of visual aids are avialable for teachers. Types of visual materials that are judged useful in microbiological safety instruction include films, film strips, projection slides, and exhibits and exhibit materials.

1. Films and Film Strips

Applicable films and film strips fall into two general categories: those that deal more or less directly with laboratory safety methods and equipment, and those that are used to impart information on certain technical methods or scientific phenomena and, in doing so, illustrate the necessary safety measures.

[1] H. J. Stack and J. D. Elkow, "Education for Safe Living," Prentice-Hall, Inc., Englewood Cliffs, N. J. (1959) 3rd Ed. p. 35.

Catalogs and lists of such aids are readily available from Government agencies, non-profit organizations, and film firms. A note of caution should be sounded, however, since not all material of this type actually succeeds in illustrating the desired safety procedures. Thus it is necessary for instructors to screen potential films or film strips carefully to assure that bad habits in safety are not actually being shown.

A number of films and film strips concerned more or less directly with laboratory safety methodology have been prepared in the past 10 years. Eleven such films and film strips are listed and described in Table 1. These are available from several sources. Teaching institutions may borrow films by applying to:

Chief, Communicable Disease Center
Public Health Service
U. S. Department of Health, Education and Welfare
Atlanta, Georgia

Films may also be borrowed from the film library of the American Society for Microbiology. All loans are free, but the borrower is expected to pay return postage and insure films at the rate of $50.00 per film.

Films listed in Table 1 may also be purchased from:

United World Films, Inc.
1445 Park Avenue
New York 29, N. Y.

2. Projection Slides

A limited number of slides that demonstrate safe laboratory principles are available from standard sources in the microbiology field, e.g., from the Visual Aids Collection of the American Society for Microbiology. Perhaps slides more effective for their intended purpose will result if the instructor attempts to develop his own collection depicting situations within his own department. This can be done personally by the instructor, through student work projects, or by assignments to individual students. Not only can faulty and correct techniques and equipment be demonstrated in this manner, but graphic summaries of data relating to accident prevention can be shown. Most departments of microbiology will have a suitable camera available.

A short list of suggested slide topics is presented below:

Correct and incorrect procedure of pipetting
Discarding pipettes
Safe types and use of syringe and needle
Use of the inoculating needle and loop
Mixing culture suspensions
Correct autopsy equipment
Preparing the animal for injection
Preparing the animal for autopsy
Streaking agar plates
Opening ampules of lyophilized material
Transferring cultures
Grinding tissue specimens
Blending tissues and cultures

3. Exhibits and Exhibit Materials

These can be employed in teaching programs in a variety of ways. Laboratory buildings often have bulletin boards and exhibit cabinets near the entrance or in the library. From time to time these areas can be used to exhibit posters or materials having to do with microbiological safety. As a general rule it is best to keep the exhibit simple and direct.

Few exhibit materials, posters, etc. are available from outside sources, but educators can consider using display items that are often offered on loan by firms selling laboratory equipment and supplies.

Other opportunities for education through exhibits present themselves. Departments of Microbiology frequently serve as the meeting place in the area for meetings of professional groups or for seminar discussions. Advanced students are often asked to attend or participate in such gatherings. On an appropriate occasion a group of students might be asked to prepare an exhibit on microbiological safety to be displayed to the audience. When the teaching institution is near or in a large city in which a national meeting or convention of a professional organization is to be held, the preparation of a safety exhibit would be a good class project. Since such meetings often have a number of commercial exhibits of laboratory equipment, including safety equipment, a class field trip to the exhibit hall is worth considering.

G. LECTURE AND DEMONSTRATION MATERIAL

This section deals with material that can be used during laboratory classes as both lecture and demonstration material. Information in the body of this report and in the bibliography will be of added assistance in planning specific instruction units.

1. Vaccination

Vaccination of laboratory personnel is to be recommended when a satisfactory and safe immunogenic preparation is available. Good immunity is conferred after vaccination against smallpox, tetanus, yellow fever, botulism, tularemia, and diphtheria. Other vaccines such as those for psittacosis, Rift Valley fever, and anthrax have or are being tried experimentally with varying degrees of success. Immunogenic preparations have not been as yet developed for a number of human diseases that have been known to occur among laboratory workers, such as dysentery, blastomycosis, brucellosis, coccidiodomycosis, glanders, histoplasmosis, infectious hepatitis, leptospirosis, and toxoplasmosis. We generally evaluate the efficiency of vaccines for laboratory workers on the basis of effectiveness in preventing disease in the general population. It must be realized, however, that the laboratory worker may be exposed to infectious microorganisms at a higher dose level than would be expected from normal public exposure and that the exposure may be by a route different from that normally expected, e.g., respiratory infection with the tularemia or anthrax organism.

2. Safety Procedures

In order to eliminate or reduce laboratory infectious hazards, it is necessary to determine what acts or accidents are most frequently responsible for creating hazards. Of course, many acts or accidents that lead to infection are known and some, such as the aspiration of infectious fluids through a pipette, are easily corrected. Other "causes" however, have not been as easy to define. The general

TABLE 1. MICROBIOLOGICAL SAFETY FILMS

U. S. Public Health Service Communicable Disease Center Catalog Number	Film Description
F-57a	The Inoculating Needle Data: 35-mm film strip, color, 10 minutes, sound. Demonstrates by laboratory experiments that bacteriological aerosols are produced from various methods of using inoculating needles on cultures and explains how such bacterial aerosols can be reduced by modifications in the inoculating techniques.
F-57c	The Hypodermic Syringe Data: 35-mm film strip, color, 12 minutes, sound. Shows and explains ways of avoiding hypodermic syringe techniques that may liberate dangerous aerosols of infectious organisms when working with cultures or inoculating experimental animals.
F-57d	The Pipette Data: 35-mm film strip, color, 10 minutes, sound. Demonstrates the hazards involved in several common techniques of using the pipette and how these techniques can be modified to reduce the danger from bacterial aerosols.
F-57e	The High-Speed Blendor Data: 35-mm film strip, color, 13 minutes, sound. Demonstrates how a high-speed blendor may liberate dangerous aerosols from cultures of infectious organisms, and suggests the use of a leak-proof blendor.
F-57f	The Centrifuge Data: 35-mm film strip, color, 12 minutes, sound. Demonstrates some of the hazards of centrifuge operations and suggests safe operating procedures.
F-57g	The Lyophilizer Data: 35-mm film strip, color, 8 minutes, sound. Demonstrates how dangerous aerosols from cultures of infectious bacteria are liberated during the lyophilization and use of dried organisms, and recommends that highly infectious organisms be lyophilized in a ventilated cabinet.
M-57	Infectious Hazards of Bacteriological Techniques Data: Motion picture, 16-mm, color, 13 minutes, sound. Demonstrates by laboratory experiments that bacteriological aerosols that may infect a technician are produced even in such procedures as shaking liquid cultures, transferring cultures, mixing with a pipette, and blending cultures. Explains ways of lessening such dangers.

TABLE 1. MICROBIOLOGICAL SAFETY FILMS (Continued)

U. S. Public Health Service Communicable Disease Center Catalog Number	Film Description
M-57a	The Inoculating Needle Data: Motion picture, 16-mm, black and white, 10 minutes, sound. High-speed photography used to show aerosol formation.
M-261	Laboratory Methods for Airborne Infections Part I, The Cloud Chamber Data: Motion picture, 16-mm, color, 30 minutes, sound. This film shows a facility used for the study of airborne infections and depicts some of the technical advances in the field of aerobiology. The system described involves an aerosol chamber equipped with complete service control for determining the effect of aerosol particle size on the respiratory virulence of pathogenic microorganisms for small laboratory animals. Prime importance is placed on safety equipment and procedures.
M-304	Laboratory Methods for Airborne Infections Part II, The Henderson Apparatus Data: Motion picture, 16-mm, color, 30 minutes, sound. In addition to a detailed explanation of the operating principles of the Henderson apparatus, the film depicts its use in several types of cabinet systems for studying bacterial and viral aerosols. Equipment of this type is an important tool for research on airborne infection. Prime importance is placed on safety equipment and procedures.
FG-382	Infectious Hazards of Bacteriological Techniques Data: Motion picture, 16-mm, color, 18 minutes, sound. Various techniques and procedures used in the bacteriological laboratory are presented, showing the dangers of infections inherent in such operations and means for minimizing or eliminating such dangers. Safety cabinets are advocated when performing hazardous operations with infectious microorganisms.

approach to teaching safe procedures should include consideration of those techniques that have been shown by experience and experiment to produce environmental contamination.

A useful method of showing how airborne contamination is produced by certain procedures, how modified procedures can lessen the hazard, how ultraviolet radiation can be used, etc., is by conducting suitable experiments with harmless microorganisms and having students sample the air. For this a suitable air-sampling device should be used. Open settling plates are of some value in classroom demonstrations but their collection efficiency is low and they tend to collect primarily the larger airborne particles that fall rapidly to surfaces rather than small particles that remain suspended for longer periods of time. Cotton swabs may also be used by the students to sample each other's floor and laboratory table-top areas, test tubes, fingers, throats, and nasal passages. It may be generally assumed that when surface sampling shows presence of the test organisms, some of these may find their way to the skin, mouth, nostrils, and lungs.

According to the type of laboratory and the courses offered, the instructor may wish to discuss and demonstrate the hazards connected with the handling and use of animals.

In animal experiments with infectious disease organisms, uncontrolled transfer of infection from animal to animal affects the validity of the experiment. Cross infection among laboratory animals also is indicative of hazards to persons handling infected animals. A number of studies have been published showing animal cross infection with such organisms as *Mycobacterium tuberculosis*, *Bacillus anthracis*, *Brucella suis*. It may be concluded that discrimination, based on the results of animal cross infection studies, is desirable when establishing animal cage requirements to insure that conditions are adequate to prevent cross infection without undue expense. In some instances the instructor may wish to demonstrate how infections can pass from one animal to another to emphasize the possible similar passage from animal to human.

3. Safety Equipment

Some, at least, of the equipment and apparatus needed should be described because they, along with some special techniques, are essential for the maintenance of safe working conditions in the infectious disease laboratory. However, the need for certain other equipment will be determined by the infectious organism in use and the type of operation being carried out.

a. Ventilated Cabinets

The source of infection in the laboratory is generally within a few inches of the worker's face. Therefore, enclosure and ventilation of the working area is an important factor in eliminating laboratory infections. A ventilated safety cabinet is a device that provides suitable table-top area for microbiological operations and has a pane of glass between the work and the worker's face. Escape of microorganisms is prevented by an inward flow of air or the maintenance of a reduced air pressure within the cabinet.

A variety of ventilated safety cabinets are available commercially. Portable cabinets of flexible plastic sheeting can be used for special operations. These are especially recommended for teaching situations because of their low cost. Modular cabinet systems, made of stainless steel joined by bolts or adhesive compounds, are recommended for highly hazardous operations. Autoclaves, disinfectant dunk baths, refrigerators, incubators, deep freezes, balances, and sinks can be attached to these cabinets. Each cabinet or cabinet system should be provided with an air filter and an exhaust blower that isolates each cabinet or system. Cabinets used with an open panel should have an inward air flow of approximately 50 linear feet per minute or, if closed (work done through attached arm-length rubber gloves), operation should be at a reduced pressure of one-half to one inch of water. Cabinets may also be supplied with vacuum, air, gas, electricity, water, drains, UV and fluorescent lighting. The safety cabinet is the most important single piece of equipment in preventing laboratory infections.

b. Centrifuge Equipment

Aerosols created by centrifuging by breakage of glass tubes or the loss of the tube stoppers constitute a laboratory hazard. It is recommended that commercially available centrifuge safety cups and heads be used. Tubes of various sizes can be placed in adapters that fit into safety trunnion cups or angle-head safety cups, and biological-tight covers are put in place. After centrifuging, the capped cups are returned to the safety cabinet for opening. The centrifuge and the cabinet are best located in the same room. Table-top centrifuges for which no safety cups are available should be placed in a closed safety cabinet during operation.

c. Pipetting Devices

Because oral pipetting of infectious or toxic materials (or even materials suspected of being infectious) should not be allowed, students should be instructed in the use of pipetting devices. A variety of pipettors are available or devices can be fabricated from material on hand. Experience has shown that acceptance of the "no mouth pipetting" rule is more easily achieved if several types of pipetting devices are available to meet the individual needs of students.

d. Devices for Decontamination and Sterilization

Autoclaves: In many laboratories the lack of a sufficient number of autoclaves suitably placed results in the acceptance of less reliable methods of sterilization or failure to sterilize some contaminated materials. For laboratory use it is essential that an autoclave have an exhaust (usually a steam ejector) and a temperature-indicating device as well as a pressure gauge. Autoclaves should be placed so as to be easily accessible to the infectious area. An autoclave for treatment of infectious materials should not be placed in the media preparation room, although an autoclave is usually required there for other purposes.

The use of a double-door autoclave between the laboratory or animal room and the clean preparation area is recommended. This allows a positive system to be established for the flow of contaminated discard materials. Autoclaves should be equipped with pressure-activated door locks. Automatic interlocks may be used to prevent the door on the clean side from being opened until a sterilization cycle has been completed.

Ethylene Oxide Chambers: When delicate instruments such as pH meters and analytical balances or heat-sensitive materials become contaminated with infectious microorganisms, adequate decontamination without destruction is usually impossible unless a sterilizing gas such as ethylene oxide is used. Therefore, it is suggested that at least one autoclave be equipped for gaseous sterilization and that students be taught the proper use of the apparatus. Carboxide gas, a mixture of ethylene oxide and carbon dioxide gases, may be used. This requires that the laboratory vacuum supply be connected to the autoclave as well as a suitable connection for tanks of carboxide. A more convenient procedure is made possible by the use of low-pressure disposable cans containing a mixture of ethylene oxide and freon gases.

These cans eliminate both the hazards involved in the handling of high-pressure gases and the need for purchase or rental of cylinders.

Vaporizors: Disinfectant vaporizers may be used to decontaminate air and surfaces in enclosed areas such as rooms or ventilated cabinets. They may also be used to decontaminate bacterial filters, refrigerators, incubators, or deep freeze units. Students should be made familiar with these techniques.

For decontamination of enclosed areas when there is no ventilating equipment in operation, one milliliter of 37% formaldehyde solution should be vaporized for each cubic foot of air space and allowed to act for six to eight hours. The initial relative humidity should be at least 80% and the temperature at least 70 F. In ventilated areas airflow should be reduced as much as possible and additional formaldehyde vaporized to treat the added air volume. Beta-propiolactone can also be used as a vapor to disinfect laboratory rooms and other spaces.

Animal Room Equipment: The frequent association of laboratory infections with animal handling warrants special attention to the procedures and equipment used for holding experimentally infected animals. There is a surprising variation in the extent to which various bacteria, viruses, and rickettsiae will cause cross infection of animals, thereby imperiling the validity of the experiment as well as providing a potential hazard to the animal handler. The need for special cages and cage racks depends upon the microorganism under study. There is a great deal of practical knowledge on this subject among experienced investigators but very little of it seems to have been published, except by casual mention in the course of reporting other results. The following equipment is recommended where applicable. If the teaching facilities do not permit or require the use of such equipment, the student should at least be made aware of their existence and purpose.

e. Ultraviolet Cage Racks

If the use of experimental animals does not include the challenge of animals with pathogens by the intranasal or respiratory route, animals may be safely placed in solid-sided metal cages with screen wire tops and the cages kept on cage racks equipped with UV lamps. Lamps used with reflectors are placed to provide a radiation barrier across the top of each cage, thereby preventing the outward escape of most airborne organisms.

f. Ventilated Animal Cages

Animals challenged with infectious organisms by the respiratory route should be held in ventilated cages until they no longer shed significant numbers of organisms from their fur or in their excretions. For organisms studied to date, this time is about three to 10 days, but it will need to be determined for each organism.

g. Respiratory Protection

In the absence of ventilated cages, and sometimes even in their presence, it is advisable for workers in infectious animal holding rooms to use respiratory protection. Use of a ventilated personnel hood is satisfactory because it provides good respiratory protection and skin and eye protection from ultraviolet radiation. Hospital gauze masks have limited value because their filtration efficiency is low for particles less than 5.0 microns in diameter. Some types of commercial respirators offer adequate protection but in this instance, if UV cage racks are used, safety goggles or shields must be worn to prevent UV eye burns. Standard-type gas masks should be demonstrated to the student.

4. Safety Facilities

In many instances the instructor will have little to do or say about the laboratory building facilities provided by the teaching institution. Economic situations are the governing factors. However, it is desirable to teach the student that control of the hazard situation in laboratories can be implemented by designing safety into the building. It is recommended that each student be required, as an out-of-class assignment, to read a recent article dealing with the design of infectious disease laboratories.

APPENDIX D

ORGANIZATIONAL ELEMENTS FOR A MICROBIOLOGICAL LABORATORY SAFETY PROGRAM

In the safety program chart (Figure 1), the basic organization layout (exclusive of the safety elements) is intended to have "universal" application. That is, most microbiological laboratories will have some or all of the basic functional elements shown. Starting with a common organizational structure, the chart shows how a safety program can be integrated into the general organization, what operational elements should be added, and what actions by management and employees are required. In a sense the program shown and described below has been over-designed, but this has been done purposely to allow selection and adaption.

Presented below is a functional outline that is keyed to the organization chart in Figure 1 and explains each element in further detail.

1. The Laboratory Director

   Gives support and backing to the entire safety program
   Acts as chairman of the accident investigation committee
   Appoints ad hoc committees to discuss special problems
   Sets up suggestion committee to consider suggestions made by employees
   Attends meetings of the laboratory safety committee, receives and takes action on their reports and recommendations.

2. Medical Officer - Safety Director

Because of the problems of infectious disease and the requirements for vaccination, chest X-rays, etc., most laboratories have a full or part-time medical officer. Sometimes the Laboratory Director may also be the Medical Officer. The size of the organization will dictate the need. It is frequently possible for the Medical Officer to serve also as the Safety Director. This is recommended provided that the person has sufficient time to perform both functions. At least the Safety Director should be a person of equal prestige who can work closely with the Medical Officer and whose academic background is acceptable to the scientists with whom he must work.

The Medical Officer operates the medical program (Paragraph 8) with a day-by-day understanding of current activities in the various laboratories. Through the Safety Director, the Medical Officer must be aware of what disease organisms are in use, what infection routes are possible, and what laboratory manipulations are being carried out. He must treat first-aid cases and injuries with an awareness of the possible contamination of the wound with disease microorganisms. The Medical Officer will render a great service if he can train the laboratory employees to be constantly aware of their health status and not to overlook minor but often important symptoms that occur early in the course of many diseases.

The Safety Director is the nucleus of the safety program. While he must have certain specific duties and exercise control over certain risk procedures because they may involve potential epidemic situations, his aim should be to encourage employees at all levels to plan and participate in their own safety program. He should take every step possible to maintain communication channels among all groups of the organization. Another responsibility is that of maintaining interest in safety.

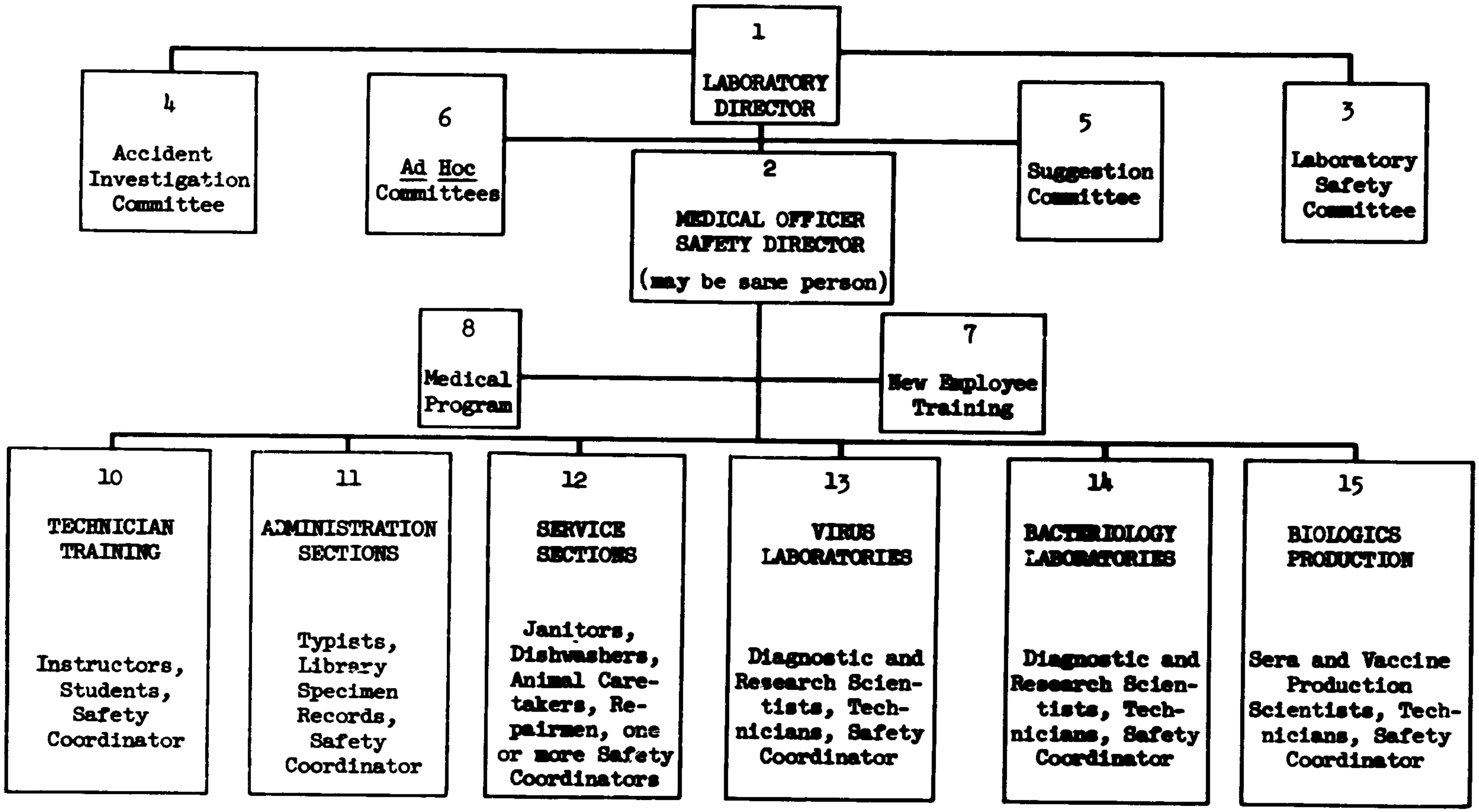


FIGURE 1. ORGANIZATIONAL ELEMENTS OF A MICROBIOLOGICAL SAFETY PROGRAM.

Other specific functions of the Safety Director are:

Serves as Chairman of the Laboratory Safety Committee
Serves on Accident Investigation Committee
Organizes safety training for new employees
Analyzes reports and information on first-aid cases and near accidents
Reviews work orders, purchase requests, and repair orders
Organizes safety regulations and directives for approval and publication by the Laboratory Director
Conducts periodic inspection of facilities.

3. Laboratory Safety Committee

This committee, if properly organized and effectively maintained, can be an important instrument in maintaining interest. It is important that the Laboratory Director make known his interest in the committee, that he participate whenever requested, and that he consider carefully all recommendations made by the committee.

Each section or subsection should have a Safety Coordinator and this individual should be a member of the committee. In some instances it may be profitable to have revolving membership, but if this is done steps must be taken to assure continuity of purpose and action.

The committee should meet at regular intervals, preferably once each month, to consider current safety problems. Members can be formed into work groups or subcommittees to investigate specific laboratory problems. The formulation of safety regulations can be one task of the committee. Whenever possible outside experts should be invited to speak or participate in the meetings.

4. Accident Investigation Committee

Membership of the committee should include the Safety Director, the Medical Officer, and other persons who may be able to contribute causal information about any accident or illness under investigation. If punitive action is taken by the committee or as a result of the committee's investigation, the difficulties in finding subsequent causes will be compounded. Usually the unpleasantness of the occupational disease or injury will be punishment enough. When enlightened discipline is required, it should be as an entirely separate action. Positive findings of the committee should be put to work by the Safety Director through the Laboratory Safety Committee.

5. Suggestion Committee

This device is mentioned because it can often be useful in stimulating employees to contribute to the operation of the organization. Many of the suggestions received will concern safety matters. Sometimes a rewards system may be incorporated. In any event a suggestion committee system should be used only after careful study of all ramifications, since if not properly organized and run it may act to the detriment of the safety effort. Obviously, the suggestion committee system is more applicable in larger organizations.

6. *Ad Hoc* Committees

In microbiological safety, the hazard scene is not only partially unknown but is also subject to change as new disease organisms are discovered and as new diagnostic techniques are used. Sometimes these changes can bring about potential laboratory hazard problems about which little is known. At other times it may be only suspected that a hazard problem exists.

When special problems arise the Laboratory Director would do well to use Ad Hoc Committees to develop information or recommendations. Outside consultants and specialists in various fields may be utilized.

7. New Employee Training

According to the size of the organization, this may be a formal or an informal function. In either case part of the training period should be devoted to acquainting the employee with the safety program and making clear to him his personal role in the accident and infection prevention endeavor. Furthermore, all new employees should receive this training. Too often it is assumed that people of higher rank entering employment do not need such indoctrination and training.

8. Medical Program

Microbiological safety programs require good integration with the medical activities. Laboratory infections have occurred because someone forgot to vaccinate new employees. Functions of the medical program should include:

Determining that each new employee meets an acceptable standard of health
Providing periodic physical examinations and chest X-rays
Administering required vaccines to personnel
Carrying out a testing program to detect subclinical infections
Providing immediate treatment in case of injury or accidental exposure.

9. Functions of All Sections

A safety program in which each employee is aware that efficient and safe actions are an integral part of his job requirements is generally a good program. When continuous safe performance becomes a part of the job goals of individuals, much progress in accident prevention should result.

Each section or operating unit should have one or more Safety Coordinators. This may be a permanent or a revolving position, but in either case it should be a part-time assignment to some person in authority at that level. The coordinator serves as a member of the Laboratory Safety Committee and, when requested, on the Accident Investigation Committee.

Functions to be carried out by or through the Safety Coordinators are:

Making initial reports and investigations of accidents
Collecting information on near-accidents and first-aid cases
Seeing that safety regulations are followed
Maintaining communication channels for distribution of information on safety
Encouraging early reporting of illnesses and exposures
Making safe performance a part of every job
Encouraging formation of subcommittees and discussion groups to consider safety problems.

10. Technician Training

Laboratories sometimes are assigned the function of training students to become laboratory technicians. Usually a course of study lasts two years, after which a certificate is issued. Inclusion of units of safety education in the training program will pay dividends. Management of safety in any situation is much easier if employees do not have to unlearn unsafe practices.

In the technician training section the instructor acts as the Safety Coordinator. The Safety Director should work closely with the instructor, providing information on safety as it may be developed in other laboratory sections. Instructional units developed in technician training courses may be useful in the new employee training program. The instructor may also encounter safety problems that should be turned over to other sections for solution.

11. Administration Sections

A variety of hazards may be encountered by persons working in these sections, not the least of which may be those dangers that arise from the employee's lack of knowledge about microbiology. For this reason particular care must be exercised in selecting the Safety Coordinator for this area. A constant danger is that the coordinator or someone else will foster a "fear complex" among nontechnical employees. The best approach is clear explanation of the hazards, with concise recommendations for avoiding exposure. For example, secretaries who handle laboratory reports, incoming specimens, etc., can usually be taught not to put pencils in their mouths and to wash their hands frequently after handling potentially contaminated materials. Specific information on decontamination techniques is supplied by the Safety Director.

Through the administrative sections, control over potential microbiological hazards can be obtained. At a laboratory in West Berlin library books were loaned to medical students who were hospitalized with tuberculosis infections. A control system was organized so that such books were decontaminated before being reissued to other persons.

The Safety Coordinator of the administration section can work closely with the Safety Director through other control measures. Requests for purchase of new laboratory apparatus or equipment, for example, can be routed to the Safety Director for his approval.

12. Service Sections

According to the size of the laboratory organization, one or more Safety Coordinators from the Service Sections may be needed. Some of the safety problems in the Service Sections are similar to those in the administrative area. Few of the people will have training in microbiology, so a direct and simple explanation must be used to avoid fear of the work. In these sections, more than in any other, the Safety Director and scientists in the organization should devote time to developing confident and safe procedures among dishwashers, animal caretakers, repairmen, etc. The relationship between these workers and the scientists is very important. Since the workmen often have no way of judging the necessity for safety measures, their adherence will often be in direct proportion to the personal confidence they hold for the scientists (or the Safety Director) as individuals.

The Safety Director operates many routine control measures through the Service Sections. Installation, repair, or work orders can be sent to the Safety Director for his review. Since supplies coming from and going to laboratories involve these sections, check points for adequacy of sterilization can be employed.

Safety during the handling of laboratory animals is often a difficult problem and special training may be needed in this area. This, however, will vary greatly according to the types of animals used and the microorganisms under study.

13, 14, and 15. Laboratory Sections

The organizational division of the laboratory functions may vary. Sometimes research is separated from routine functions but more often, since different types of facilities are required, the division is made according to specialities such as bacteriology, virology, mycology, and serology. Each laboratory section should have a Safety Coordinator. The relationship of the Safety Director with these sections, however, may be quite different from those he has with other sections, because the director will find it impossible to be technically informed about all of the operations going on. Through the coordinator an effort should be made to maintain interest in microbiological safety. Participation is probably the principal device to use. Various scientists and technicians should be asked to advise other sections on various matters; certain groups can be asked to do research to solve current safety problems. Participation, followed by recognition, will do much to maintain a well-integrated safety program. Scientists should be encouraged to design safety into new techniques and procedures that are developed.

APPENDIX E

SAFETY RULES FOR INFECTIOUS DISEASE LABORATORIES

A. GENERAL

1. Only authorized employees, students, and visitors should be allowed to enter infectious disease laboratories or utility rooms and attics serving these laboratories.

2. Food, candy, gum, or beverages for human consumption should not be taken into infectious disease laboratories.

3. Smoking should not be permitted in any area in which work on infectious or toxic substances is in progress. Employees who have been working with infectious materials should thoroughly wash and disinfect their hands before smoking.

4. Library books and journals should not be taken into rooms where work with infectious agents is in progress.

5. An effort should be made to keep all other surplus materials and equipment out of these rooms.

6. Drinking fountains should be the sole source of water for drinking by human occupants.

7. According to the level of risk, the wearing of laboratory or protective clothing may be required for persons entering infectious disease laboratory rooms. Likewise, showers with a germicidal soap may be required before exit.

8. Laboratory clothing should not be worn in clean areas of the building.

B. DISINFECTION AND STERILIZATION

1. All infectious or toxic materials, equipment, or apparatus should be autoclaved or otherwise sterilized before being washed or disposed of. Each individual working with infectious material should be responsible for its sterilization before disposal.

2. Infectious or toxic materials should not be placed in autoclaves overnight in anticipation of autoclaving the next day.

3. To minimize hazard to firemen or disaster crews, at the close of each work day all infectious or toxic material should be (i) placed in the refrigerator, (ii) placed in the incubator, or (iii) autoclaved or otherwise sterilized before the building is closed.

4. Autoclaves should be checked for operating efficiency by the frequent use of Diack, or equivalent, controls.

5. All laboratory rooms containing infectious or toxic substances should designate separate areas or containers labeled:

INFECTIOUS - TO BE AUTOCLAVED
or
NOT INFECTIOUS - TO BE CLEANED

6. Floors, laboratory benches, and other surfaces in buildings in which infectious substances are handled should be disinfected with a suitable germicide as often as deemed necessary by the supervisors. After completion of operations involving plating, pipetting, centrifuging, and similar procedures with infectious substances, the surroundings should be disinfected.

7. Floor drains throughout the building should be flooded with water or disinfectant at least once each week in order to fill traps and prevent backing up of sewer gases.

8. Floors should be swept with push brooms only. The use of a floor-sweeping compound is recommended because of its effectiveness in lowering the number of airborne organisms. Water used to mop floors should contain a disinfectant.

9. Stock solutions of suitable disinfectants should be maintained in each laboratory for disinfection.

10. All laboratories should be sprayed with insecticides as often as necessary to control flies and other insects.

11. No infectious substances should be allowed to enter the building drainage system without prior sterilization.

12. Mechanical garbage disposal units should not be installed for use in disposing of contaminated wastes. These units release considerable amounts of aerosol.

C. SAFETY CABINETS AND SIMILAR DEVICES

1. A ventilated safety cabinet should be used for all procedures with infectious substances such as opening of test tubes, flasks, and bottles; using pipettes; making dilutions; inoculating; autopsying animals; grinding; blending; opening lyophile tubes; operating a sonic vibrator; operating a standard table model centrifuge, etc.

2. A safety box or safety shaker tray should be used to house or safeguard all containers of infectious substances on shaking machines.

3. A safety centrifuge cabinet or safety centrifuge cup should be used to house or safeguard all centrifuging of infectious substances. When centrifuging is done in a ventilated cabinet, the glove panel should be in place with the glove ports covered. A centrifuge in operation creates reverse air currents that may cause escape of agent from an open cabinet.

4. A respirator or gas mask should be worn when changing a glove or gloves attached to a cabinet if an infectious aerosol may possibly be present in the cabinet.

<u>Pipettes</u>

1. No infectious or toxic materials should be pipetted by mouth.

2. No infectious mixtures should be prepared by bubbling expiratory air through a liquid with a pipette.

3. No infectious material should be blown out of pipettes.

4. Pipettes used for the pipetting of infectious or toxic materials should be plugged with cotton.

5. Contaminated pipettes should be placed horizontally in a pan containing enough suitable disinfectant to allow complete immersion. They should not be placed vertically in a cylinder. The pan and pipettes should be autoclaved as a unit and replaced by a clean pan with fresh disinfectant.

Syringes

1. Only syringes of the Luer-Lok type should be used with infectious materials.

2. Use an alcohol-soaked pledget around the stopper and needle when removing a syringe and needle from a rubber-stoppered vaccine bottle.

3. Expel excess fluid and bubbles from a syringe vertically into a cotton pledget soaked with disinfectant, or into a small bottle of cotton.

4. Before and after injection of an animal, swab the site of injection with a disinfectant.

General Precautions and Recommendations

1. Before centrifuging, inspect tubes for cracks, inspect the inside of the trunnion cup for rough walls caused by erosion or adhering matter, and carefully remove bits of glass from the rubber cushion. A germicidal solution added between the tube and trunnion cup not only disinfects the outer surfaces of both of these, but also provides an excellent cushion against shocks that might otherwise break the tube.

2. Avoid decanting centrifuge tubes. If you must do so, afterwards wipe off the outer rim with a disinfectant; otherwise, the infectious fluid will spin off as an aerosol. Avoid filling the tube to the point that the rim ever becomes wet with culture.

3. Water baths and Warburg baths used to inactivate, incubate, or test infectious substances should contain a disinfectant. For cold water baths, 70% propylene glycol is recommended.

4. When the building vacuum line is used, suitable traps or filters should be interposed to insure that pathogens do not enter the fixed system.

5. Deep-freeze and dry-ice chests and refrigerators should be checked and cleaned out periodically to remove any ampoules, tubes, etc., containing infectious material that may have broken during storage. Use rubber gloves and respiratory protection during this cleaning. All infectious or toxic material stored in refrigerators or deep freezes should be properly labeled.

6. Insure that all virulent fluid cultures or viable powdered infectious materials in glass vessels are transported, incubated, and stored in easily handled nonbreakable leakproof containers that are large enough to contain all the fluid or powder in case of leakage or breakage of the glass vessel.

7. All inoculated petri plates or other inoculated solid media should be transported and incubated in leakproof pans or other leakproof containers.

8. Care must be exercised in the use of membrane filters to obtain sterile filtrates of infectious materials. Because of the fragility of the membrane and other factors, such filtrates cannot be handled as noninfectious until culture or other tests have proved their sterility.

9. Develop the habit of keeping your hands away from your mouth, nose, eyes, and face. This habit may prevent self-inoculation.

10. No person should work alone on an extremely hazardous operation.

11. Broth cultures should be shaken in a manner that avoids wetting the plug or cap.

12. Diagnostic serum specimens carrying a risk of infectious hepatitis should be handled with rubber gloves.

D. ANIMALS

Animal Cages

All animal cages should be marked to indicate the following information:

1) Normal animals

2) Animals inoculated with noninfectious material

3) Animals inoculated with infectious substances

Infected Animal Cages

Cages used for infected animals should be cared for in the following manner:

1. Careful handling procedures should be employed to minimize the dissemination of dust from cage refuse and animals.

2. Cages should be sterilized by autoclaving. Refuse, bowls, and watering devices will remain in the cage during sterilization.

3. All watering devices should be of the non-drip type.

4. Each cage should be examined each morning and at each feeding time so that dead animals can be removed.

Handling Infected Animals

1. Especial attention should be given to the humane treatment of all laboratory animals in accordance with the Principles of Laboratory Animal Care as promulgated by the National Society for Medical Research.

2. Monkeys should be tuberculin-tested at appropriate intervals.

3. Persons regularly handling monkeys should receive periodic chest X-ray examination and other appropriate tuberculosis prophylactic procedures.

4. When animals are to be injected with pathogenic material, the animal caretaker should wear protective gloves and the laboratory workers should wear surgeons gloves. Every effort should be made to restrain the animal to avoid accidents that may result in disseminating infectious material. Such inoculations should be carried out in a ventilated cabinet.

5. Heavy gloves should be worn when feeding, watering, or removing infected animals. Under no circumstances will the bare hands be placed in the cage to move any object.

6. Animals in cages with shavings should be transferred to clean cages twice each week unless otherwise directed by the supervisor. If cages have false screen platforms, the catch pan should be replaced before it becomes full.

7. Infected animals to be transferred between buildings should be placed in aerosol-proof containers.

Animal Rooms

1. Doors to animal rooms should be kept closed at all times except for necessary entrance and exit.

2. Unauthorized persons should not be permitted entry to animal rooms.

3. A container of disinfectant should be kept in each animal room for disinfecting gloves and for general decontamination. Floors, walls, and cage racks should be washed with disinfectant frequently. Gloves should be sterilized by autoclaving.

4. Floor drains in animal rooms should be flooded with water or disinfectant periodically to prevent backing up of sewer gases.

5. Shavings or other refuse on floors should not be washed down the floor drain.

6. Sodium fluoracetate (T-1080), or similarly effective poison, should be maintained in animal rooms to kill escaped rodents.

7. Special care will be taken to prevent live animals, especially mice, from finding their way into disposable trash.

Necropsy of Infected Animals

1. Necropsy of infected animals should be carried out in ventilated safety cabinets.

2. Rubber gloves should be worn when performing necropsies.

3. Surgeons' gowns should be worn over laboratory clothing during necropsies.

4. Fur of the animal should be wet with a suitable disinfectant.

5. Animals should be pinned down or fastened on wood or metal in a metal tray.

6. Upon completion of autopsy, all potentially contaminated material should be placed in suitable containers and sterilized immediately.

7. Instruments should be placed in a horizontal bath containing a suitable disinfectant or left in the autopsy tray. The entire tray should be autoclaved at the conclusion of the operation.

8. The inside of the ventilated cabinet and other potentially contaminated surfaces should be disinfected with a suitable germicide.

9. Grossly contaminated rubber gloves should be cleaned in disinfectant before removal from the hands, preparatory to sterilization.

10. Dead animals should be placed in proper leakproof containers and thoroughly autoclaved before being placed outside for removal and incineration.

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13 ABSTRACT

This research was conducted to uncover causal factors of accidental infections and injuries in microbiological laboratories. Less than 20 per cent of the infections were caused by recognized and recorded accidents. As many as 80 per cent of the infections were caused by unsafe acts that occurred without realization or recognition. These are described as "micro-mistakes" resulting in the release of undetected amounts of pathogens to the workers' environment. More than three-quarters of the injuries were caused by unsafe acts. Unsafe conditions caused 10 per cent of the accidents. Dried cultures, infected eggs, and aerosolized cultures were the most hazardous forms of infectious microorganisms. Younger workers and those with less technical training experienced more accidents than older workers or those with more training. Interviews with accident-involved and accident-free persons provided insight into the role of human factors. Accident-involved persons tended to lack accident perception ability and to be inflexible in their work habits. They also were inclined toward excessive risk taking, working at excessive speeds, and intentional violation of regulations. Accident-free workers were more conservative in evaluating safety and seemed able to develop defensive work habits.

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